THE MICROSCOPE

CONRAD BECK

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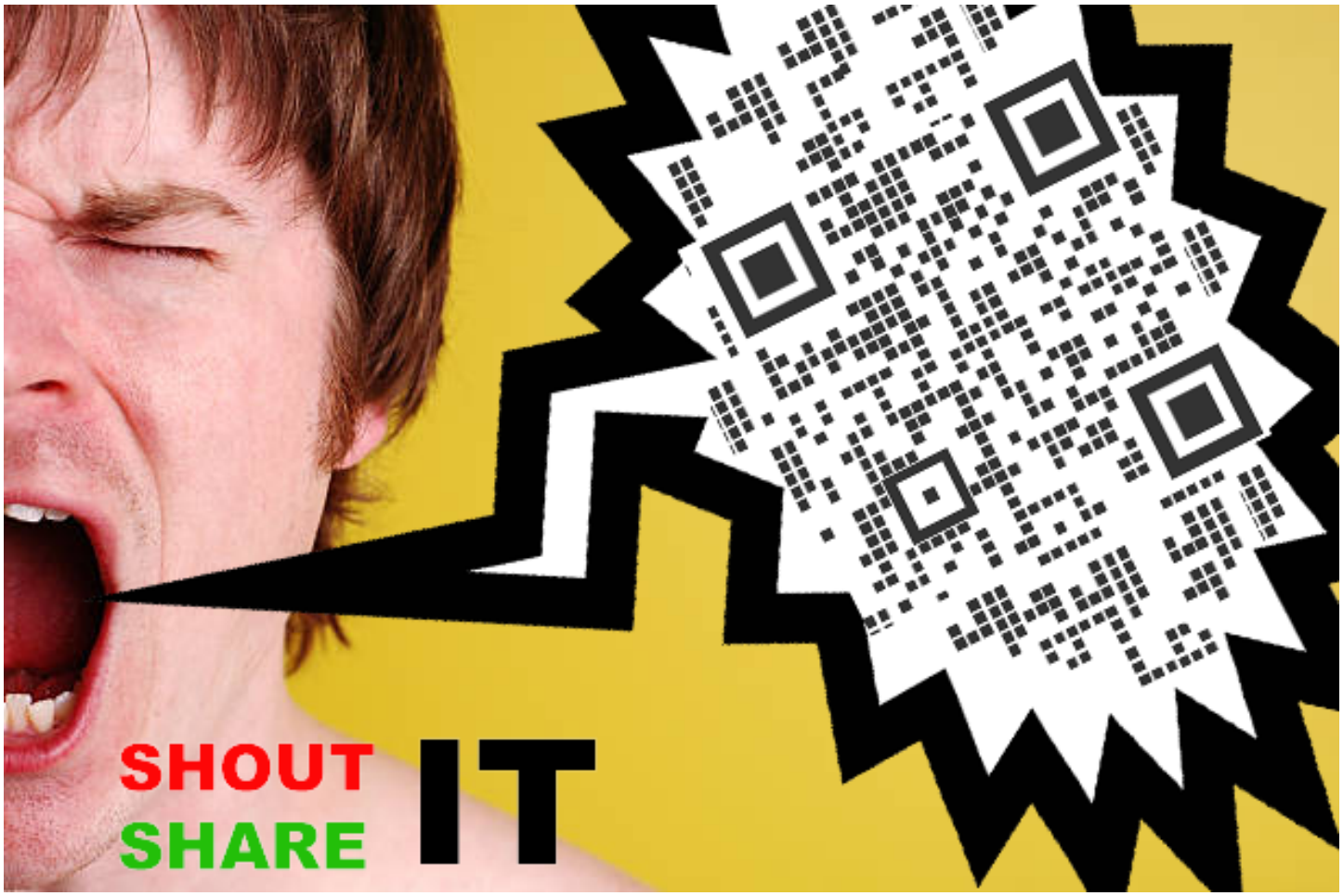
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THE MICROSCOPE

THE MICROSCOPE

A SIMPLE HANDBOOK

BY

CONRAD BECK

FIRST EDITION

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PREFACE

This book is intended as a guide to the use of the microscope. The correct use of the instrument follows directly from a knowledge of the functions of the different parts. It has therefore been found best to develop the method of manipulation in the course of the descriptions of the component portions. Such particulars as are given of the principles of its optical construction are of the simplest character, and their comprehension requires no optical knowledge. Certain theoretical matters are stated in this book, but are not explained. Some of the descriptions may appear to be extremely elementary to experienced microscopists, but it is hoped that even they may find useful matter which is not available in the ordinary text-books.

The author hopes to publish a further volume at a later date, which will deal with the optical theory and the use of the microscope in greater detail.

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K. Iris diaphragm for varying the light.

L. Limb for holding the body and stage.

M. Body for carrying the observing lenses.

N. Drawtube for lengthening body.

N1. Drawtube stop to prevent reflections from tube entering eyepiece.

O. Eyepiece, combination of lenses nearest observer's eye.

P. Fine adjustment for delicate focussing of body.

Q. Coarse adjustment for rapid focussing of body.

R. Object glass, combination of lenses nearest the object.

S. Nosepiece with universal screw for carrying object glasses.

T. Eyepoint position where all emergent light passes through a small area and where observer's eye should be placed.

U. Position where the primary image formed by the object glass is produced.

V. Position where final virtual image formed by eyepiece is produced.

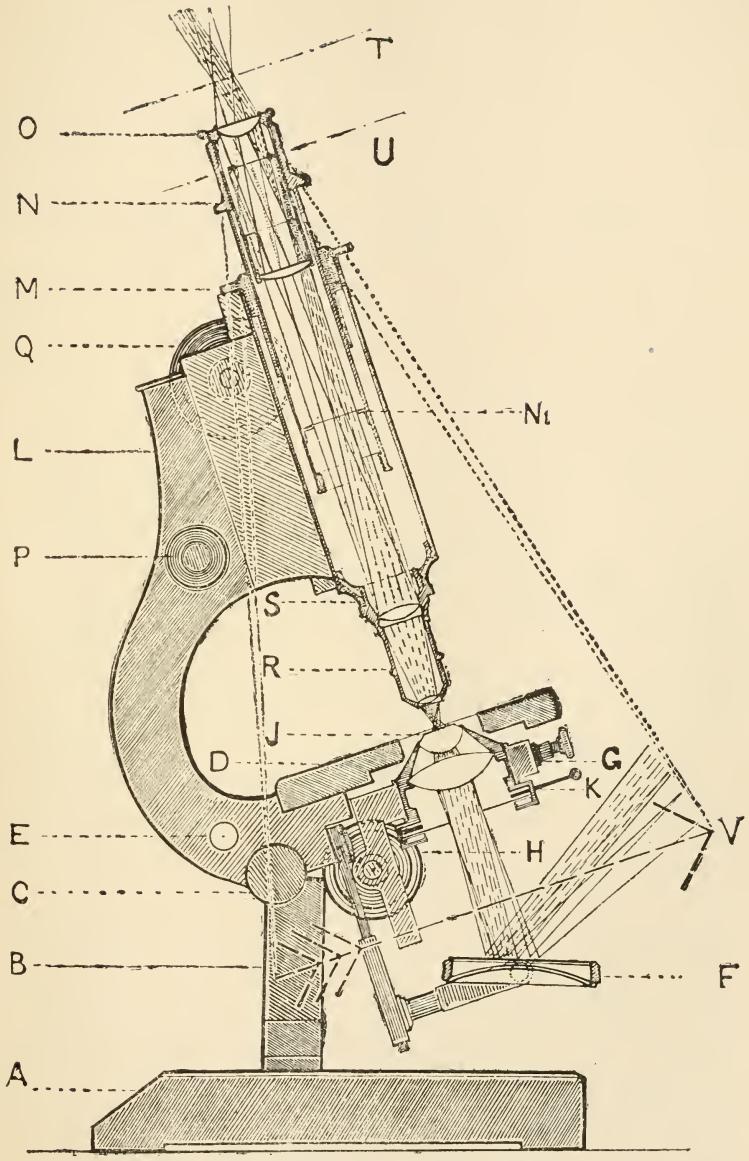


Fig. 1.—Diagram of a Microscope.

THE MICROSCOPE

CHAPTER I

A SIMPLE DESCRIPTION OF THE MICROSCOPE

The microscope is an apparatus for producing an enlarged image of a small object. In its complete form it is an elaborate instrument, but to understand its construction it may be looked upon as a complex form of magnifying lens with the addition of means for making delicate adjustments both for moving the lens and the object and for obtaining special forms of illumination. It consists primarily of three parts—the body, which carries the observing lenses, the stand or framework, and the illumination apparatus.

The body.

The body (M) carries an object glass (R), which is attached to the object end by a standard size screw thread, and an eyepiece (O), which slips loosely into the tube at the eye end in a standard size fitting. It has a telescopic tube, called a draw-tube (N), for varying the distance between the object glass and the eyepiece, and a diaphragm (N1) to prevent reflections from the inner surfaces of the tubes from entering the eye.

The body and its lenses combined form the magnifying apparatus.

The object to be examined is placed on the stage (D) of the microscope. The object glass if used by itself acts in the same manner as a lantern lens. It throws an enlarged picture of the object to a position (U) at the upper end of the body, just as a lantern lens throws an enlarged picture of a small lantern slide upon a white screen, but instead of its being thrown upon a white screen it is thrown into space. This image is examined with a magnifying lens called the eyepiece (O), by which it is further magnified. If the primary image were projected upon a lantern screen and one were to cut a hole in the screen and stand behind it with a magnifying lens focussed upon the plane of the screen, one would have the same kind of instrument as a microscope on a large and inconvenient scale.

The object glass.

The object glass (R) in the earliest instruments was a single double convex lens (Fig. 2); it gave an enlarged but very imperfect picture of small objects, the outlines were surrounded by coloured fringes, and the details were fuzzy and indistinct. Such lenses were made several hundred years ago, but in the early part of the nineteenth century is was discovered that the defects of a single lens could be overcome by using several lenses in combination, made of different kinds of glass and of suitable shapes and sizes.

Fig. 2.

Focal length of object glass.

Modern object glasses are made of different powers to give different magnifications in the primary image, and, in general, the more an object glass magnifies, the larger the number of lenses that are required to produce a perfect image. For instance, Fig. 3 shows the optical construction of the 2/3-inch (16-mm.), 1/6-inch(4-mm.), and 1/12-inch (2-mm.) object glasses.

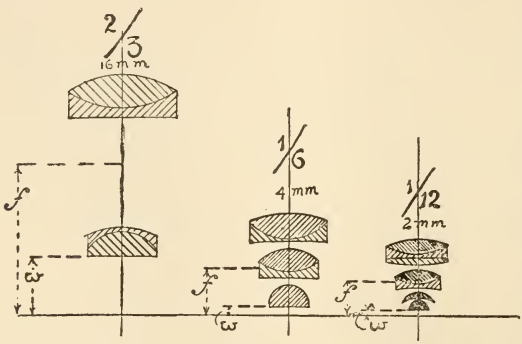


Fig. 3.—f = focal length; w = working distance.

The name 2/3, 1/6, or 1/12 inch, as applied to an object glass, represents its focal length. It indicates its magnifying power. If an ordinary single lens of 2-inch focal length is used as a hand magnifying glass, it has to be placed about 2 inches from an object to give a clear image, and the 2/3, 1/6, and 1/12 inch require to be placed at about these respective distances from the object when in use—thus the higher the magnifying power of a lens, the closer it must be to the object.

Working distance.

Object glasses are not single lenses, but are composed of several, and consequently the focal distance is measured from a point about half-way between the front and back surfaces of the component lenses. The distance between the foremost lens and the object is, therefore, always considerably less than the true focal distance. This is called the working distance to signify the space between the end of the microscope and the object when it is so adjusted that a clear picture is obtained, or when it is, as it is called, "in focus." A list of the working distances of different object glasses is given on page 82.

An examination of the diagram (Fig. 1) on page 9 illustrates

the formation of the images. An enlarged picture of an object placed upon the stage (D) is formed in the neighbourhood of the eyepiece at U, and the eyepiece again magnifies this image, projecting the light into the eye as if it came from an object situated at V.

Eyepiece. The eye, when placed in a small area (T) through which all light passes, and which is known as the eyepoint, sees the final picture of the object as if it were a real object placed at V, 10 inches from the eye.

Virtual image. It is assumed for convenience of measurement that this picture is actually 10 inches away, though it may be formed at a somewhat different position according to the adjustment or condition of the observer's eye. Whether the virtual image is actually at 6, 10, or 20 inches is of no importance. It makes no difference to the size of the picture, because when the virtual image is formed farther away it becomes proportionally larger. In Fig. 4, if E is the eye and O O′ O″ are objects of different sizes, they produce the same size pictures in the eye if placed at such distances that they subtend the same angle.

Magnifying power. The magnifying power of the microscope will depend upon the size of this final image formed at V (Fig. 1) compared with the size of the object being examined. In this connection it should be understood that if a microscope is said to magnify 100 diameters, it means that the picture that is seen is 100 times as long and 100 times as wide as the object would appear if it were taken from the stage (D, Fig. 1) and placed in the position V, 10 inches from the eye.

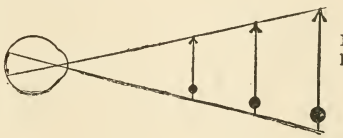


FIG. 4.

In order to express how much larger an object appears when seen through the microscope than when seen by the naked eye, a standard distance must be taken, because an object appears to the naked eye to be of different sizes at different distances. A sixpence is almost invisible at a distance of 100 yards, but it is a large object at 8 inches. Therefore, some standard must be taken for comparison purposes, and 10 inches has been universally adopted. The magnifying power of a microscope always denotes the relative size of the picture compared with that of the original object when placed 10 inches from the eye.

Different methods of obtaining magnifying power. If a microscope has a magnifying power of 100, such magnification may be produced by different methods. The object glass may magnify the object twenty times in the primary image, and the eyepiece increasing the primary image five times will give a total of a hundred. This magnification may also be pro-

duced by a lower power object glass which magnifies the object ten times, and a higher power eyepiece which magnifies it again by ten. The same result is obtained as far as magnifying power is concerned, but a different result as regards the quality of the image.

Another method of varying the magnifying power is by increasing the distance between the object glass and the eyepiece. To enable this to be done the microscope is supplied with a sliding drawtube (N), which allows the tube length to be varied from 140 to 200 mm. The reason for this increase in magnification is well illustrated by reference to the lantern, in which case the lantern lens gives a larger picture when it projects it upon a screen that is at a greater distance. In the same way the microscope object glass produces a more highly magnified primary image if by slight adjustment in the focussing of the instrument the picture is formed at a greater distance, and the drawtube of the microscope is extended so as to examine the picture formed at this greater distance.

Field of view.

The " field of view " is a term applied to the size of the object that can be seen at one time by means of the microscope. To assist in increasing the size of field an eyepiece is made of two lenses instead of a single one. The lower field lens is situated below the position U (Fig. 1), where the primary image is produced, and increases the field of view while the upper lens does the magnifying.

Suppose that the apparent field of view is a circle of about 8 inches diameter at the position V, where the final image seen through the microscope appears to be. It is evident that with a microscope magnifying 100 diameters, the size of the largest object that can be observed at one time is only 1/100 the size of this field, or about 1/12 inch, so that for this reason alone it is important that a microscope should possess a means of varying the magnifying power. It is sometimes desirable to examine a large area of an object with a small magnifying power, at others a small area with a large magnifying power. A table of the fields of view given by different lenses appears on page 82. The question arises as to whether it is preferable to vary this magnifying power by means of changing the eyepiece, by means of changing the object glass, or by means of lengthening the drawtube.

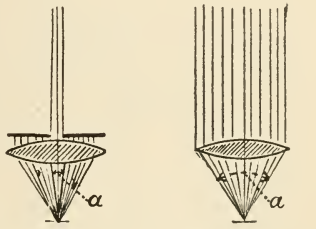
This is influenced by an optical consideration of great importance.

Aperture.

In the early days, before it was understood how to correct the errors of a single lens, microscopes were constructed in which the object glass was a single lens, the defects of which were reduced by putting a very small aperture—almost a pin-hole—in front or behind this lens. This meant that only an extremely fine cone of light from each point of the object could

enter the instrument (see Fig. 5). It was soon found that when this was the case, although great magnifying power could be obtained, fine detail could not be seen, but merely a representation on a larger scale of the coarse structure which could readily be seen with a lower magnifying power.

In order that an advantage should be obtained from the use of higher magnifying power, it was necessary to admit into the microscope a correspondingly larger cone of light from each point of the object, as unless this were done, no advantage could be obtained in the observation of fine details. Such a plan had the further advantage that it collected a larger amount of light and rendered the object more brilliant. The size of the cone of light admitted into the microscope from each point of the object is called the aperture (*a*, Fig. 5). It is expressed either by the angle of the cone of light entering the microscope or by a figure called the numerical aperture, or N.A.



Small Aperture Lens. Large Aperture Lens.

FIG. 5.—*a* = angular aperture.

Limit of vision dependent on aperture.

The aperture is of such paramount importance, that the limit of what can be seen with the microscope does not depend upon what magnifying power can be obtained, but upon what size cone of light can be collected from the object by means of the object glass; and lenses can be made with a much higher magnifying power, but they cannot be made with a larger aperture, than those in use at the present time.

The aperture, therefore, has a direct bearing upon the best method of increasing magnifying power, because, if an object glass can only admit a certain aperture of light, the use of an eyepiece does not alter this property, and therefore to increase the magnifying power by high eyepieces is of no service, when carried beyond that power which is sufficient to enable the detail that can be shown by the aperture of a particular object glass to be seen.

Best method of increasing magnifying power.

The best method of increasing the magnifying power is, therefore, by changing the object glass. Most object glasses have sufficient aperture to allow of the use of an eyepiece of as high a power as 15, but, in general, magnification of more than 10 by means of the eyepiece should only be used in special cases, and the object glass should be changed rather than the eyepiece.

Standard length of body.

The same reason makes it undesirable to depend for increased magnifying power upon extending the drawtube of the microscope, and the more so in this case because the object glass can only be constructed to work at its best with a particular length

of body. To obtain the most perfect results a tube length of 160 mm. should be used—the drawtube of the microscope is graduated, and can be set at this figure. If a revolving nosepiece is in use, this lengthens the body 15 mm., and the drawtube should be set at 145 mm. instead of 160 mm.; with a Sloan object glass changer measuring 10 mm. it should be set at 150 mm.

Thickness of cover glass.

The thickness of the cover glass used over the object has no effect with an immersion lens and but slight influence with the low powers, but is a matter of importance with a high-power dry lens. A 1/6-inch object glass can only be optically correct for one thickness of cover glass, and it is most important to always use those known as No. 1 thickness. The object glasses, unless otherwise ordered, are always made for a thickness of ·007 inch (·18 mm.), which is the average thickness of No. 1 cover glass. Thicker cover glasses should only be used for objects to be examined with low powers.

Apertures suitable for different powers.

The delineation of fine structure depends upon the aperture of the object glass being sufficiently large to produce an image of this fine structure, but combined with this it must possess a sufficient degree of magnification to enable this image to be clearly seen. We may know that the finest lines of an etching or steel engraving exist in a print, but it may be necessary to magnify the image in order to make them visible as single lines to the eye. If the print is magnified further, the fine lines appear thicker, but no further fine lines are there to be seen. Thus lines which are invisible require a certain degree of magnification to see them clearly, but extra magnification beyond this point is useless. So with a microscope object glass, it must possess a large enough aperture to produce the detail in the image, and the magnifying power need not be more than enough to enable the eye to see it clearly.

Table of apertures and powers.

Each object glass has a particular aperture, sufficient to form an image of all the detail that can be seen with the magnifying power given by it in conjunction with a moderate eyepiece. The following table gives the apertures of standard object glasses:

Focus.	Angular Aperture.	Numerical Aperture.	Initial Magnifying Power.	Magnifying Power with Eyepiece.		
				42 mm.	25 mm.	17 mm.
1½ in. = 40 mm. .	19°	·16	3	20	34	50
1½ in. = 32 mm. .	17°	·15	4	25	45	65
2/3 in. = 16 mm. .	32°	·28	10	62	110	155
1/3 in. = 8 mm. .	60°	·5	18·5	115	200	285
1/6 in. = 4 mm. .	116°	·85	40	285	490	690
1/8 in. oil immersion = 3 mm. .	—	·95	60	427	735	1,015
1/12 in. oil immersion = 2 mm. .	—	1·3	90	530	900	1,275

Angle in air compared with that in glass.

The 1/6-inch is receiving from the object, cones of light of 116°, as shown in Fig. 6. It could not be made to collect a very much larger angle of light because it cannot be used in absolute contact with the object. Sufficient space must be provided for a thin glass cover and a small distance for focussing adjustment. It will be noticed in Fig. 6 that the cone of light, which is 116° as it enters the object glass, is only 68° when it passes through the object. It is spread out by refraction as it enters the air between the cover glass and the lens. If the air space between the cover glass and the lens could be filled up with glass, this spreading out of the cone would not occur, and the cone of light would remain 68° when it entered the lens. As far as the power of depicting detail is concerned it would be equal to a 116° cone in air. It is the same body of light and has just the same properties in this respect. If therefore the space between the object and the lens is glass throughout, a larger angled cone than 68° can be collected by the object glass, and a greater power of depicting detail, what is known as resolution, can be reached, and a further power of seeing fine structure obtained.

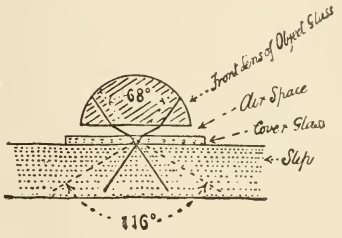


FIG. 6.

Immersion object glasses.

Cedar-wood oil is a liquid which has the optical properties of glass, and if a drop of this oil is placed between the front of the object glass and the cover glass, the whole distance between the object and the lens is equivalent to glass. A much larger effective aperture can thus be obtained with corresponding increase in resolution.

Thus object glasses of higher power than 1/6 inch (4 mm.) are generally what are called immersion object glasses. They are so constructed that a drop of cedar-wood oil must be placed on the front lens so that it connects it to the object being examined.

Numerical aperture.

The method of describing the aperture by the term numerical aperture (N.A.) instead of by the actual angle of the cone is to enable the resolving power of a microscope to be correctly stated. A 1/12-inch oil-immersion object glass is generally made to admit an angle in glass of 117°, which corresponds to an angle of more than 180° in air. It is almost the same actual angle as the 1/6-inch admits from air, but the numerical aperture (N.A.) which gives its true resolving power is 1·3 N.A., while that of the 1/6-inch is only ·85 N.A.

Dry lenses such as the 1/6-inch cannot be used with cedar-wood oil as immersion lenses, and immersion lenses cannot

be used without the cedar-wood oil because the lenses must be specially constructed for the conditions under which they are used.

Immersion fluids.

No immersion fluid but cedar-wood oil, or a fluid sold for the purpose with exactly the same optical properties, must be used. Water, paraffin, or several other substitutes which are sometimes inadvertently employed, entirely destroy the fine quality of the image formed by an oil-immersion lens.

Flatness of field.

In every optical instrument the centre of the field gives the finest definition, and the object being examined should be placed near the centre. An absolutely flat field is incompatible with the finest definition in the centre, and although in certain types of telescopes and photographic lenses the importance of a flat field is so great that a compromise is made, no deterioration of the central image can be allowed in the microscope.

Depth of focus.

The penetration or depth of an object glass or the number of different layers of an object that can be seen sharply at the same time with a microscope is very small. With lenses of a high aperture, and therefore in general of a high magnifying power, the penetration decreases at a very rapid rate, and the power of seeing different planes sharply must depend on adjusting the instrument. It has been said that the depth of focus of a high-power microscope is really the fine focussing adjustment. The fine adjustment in the hands of a skilled observer is in constant motion, focussing first to one plane and then to another; by this means a perception of depth is obtained which could never be given by an object glass fixed at one focus.

The penetration of the microscope may be increased by inserting a stop with a small aperture immediately behind the object glass, but such a method reduces the aperture and consequently the detail that can be seen. It is seldom adopted except for photographing certain objects where the image from the upper or lower portion of the object obscures the layer being photographed, or for photographing objects with comparatively coarse structure. An iris diaphragm is made that will screw into the body of the microscope between it and the object glass for this purpose.

Coarse focussing adjustment.

There is only one position in relation to the lenses where an object can be placed to give a perfectly clear picture. This position is generally called the focus, and the microscope is said to be "in focus" when it is so adjusted that the object is in this position. It is more convenient to effect this adjustment by moving the body which carries the lenses rather than by moving the object. The coarse focussing adjustment is actuated by a helical rack and pinion which moves the body along a slide towards or away from the object. Turning the milled head so that its upper edge moves towards the observer, raises the body; away from the observer, lowers it. It is a sufficiently delicate

motion for focussing with object glasses of lower power than 1/6-inch (4 mm.).

Fine focussing adjustment.

The fine focussing adjustment does exactly the same as the coarse adjustment, but the movement is far more delicate: it is actuated by a micrometer screw and a lever moving the whole body along a second slide. A complete turn of the screw moves the body about a quarter of a millimetre. Turning the fine adjustment milled heads moves the body in the same direction as those of the coarse adjustment. In the "Standard" microscope the left-hand milled head is twice as delicate a motion as that on the right-hand side. The fine adjustment is required for the focussing of high powers and for examining the different layers of an object.

The best method of focussing.

In moving the body of the microscope up and down to obtain the correct focus, care is required to prevent the front of the object glass being forced into contact with the object by racking it too far down. It is easy to break a valuable specimen by this means; and although for its protection the metal mount of the object glass projects slightly in front of the front lens, it is delicate in construction, and can be damaged by being brought into contact with the specimen.

Experienced microscopists can focus a lens downwards and stop at the position where the object is sharply seen, but it is unsafe. The correct method is to set the body of the microscope so that the front of the object glass almost but not quite touches the object, and then to rack backwards, turning the milled heads so that the upper portion turns towards the observer, and raise the body until the correct focus is found. With high-power object glasses, especially oil-immersion lenses, this method is not so easy because the distance of the correct focus may be below the point at which the body has been set in the first instance. If, however, the slow motion is used to make the final adjustment, damage is not likely to occur, as it lowers the body very gradually, and the latter is only pressed down upon the object by a spring. When using an oil-immersion lens a drop of cedar-wood oil should be placed on the object glass, and the body of the microscope racked down until the drop of oil touches the cover; the final focussing can then be done with the fine adjustment.

Some objects are so transparent that it is quite easy to pass by the focus and miss the correct position. In these cases dust on the cover glass may be focussed first, and the fine adjustment lowered by an amount representing the thickness of the cover glass. If the slide be moved backwards and forwards on the stage during the process of focussing, the movement will be seen directly the correct position is nearly reached.

It may appear absurd to mention that if a slide happens to have been placed on the stage upside down a high-power object glass will not focus through the thick glass slip, but the writer

has more than once made such a mistake and wondered why he could not focus his specimen.

Revolving nosepiece.

The nosepiece (S) of a microscope is the lower end of the body (M) provided with a screw for attaching object glasses. A revolving nosepiece is an appliance which screws into the nosepiece and which carries a revolving plate into which two or three object glasses can be fixed, known as double or triple nosepieces respectively. By rotating the revolving plate each object glass can be rapidly brought into use, being held in the correct position by a spring clip. The best form is made so that no dust can drop into the back of the object glasses and they can be safely left attached to the microscope. The extra length of the body caused by the length of a nosepiece is 15 mm., and the drawtube should be closed by that amount or set at 145 mm. instead of 160 mm.

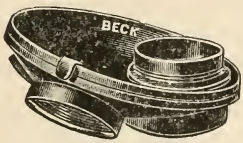


FIG. 7.—No. 3301, Dust-tight Triple Nosepiece.

Sloan object changer.

An object glass changer is an apparatus for rapidly changing the object glasses by another method. Each object glass is screwed into a fitting which slips into an adapter that is fixed to the nosepiece of the microscope, and as each fitting is provided with two adjustable abutment screws the object glasses can be individually adjusted so that they exactly register as regards the position of the field of view. Changing an object glass by this means is nearly as rapid and more accurate than that of a revolving nosepiece, and is far more convenient when the object glasses are to be used on different instruments or where more than three are used.

It consists of an adapter which has on one side a sloping projection (A), and on the other a clamp screw (B) which actuates a bevelled nut (C). The adapter is clamped to the nosepiece of the microscope by a screwed ring (D), which is provided with slots, into which a half-penny will fit for tightening it up.

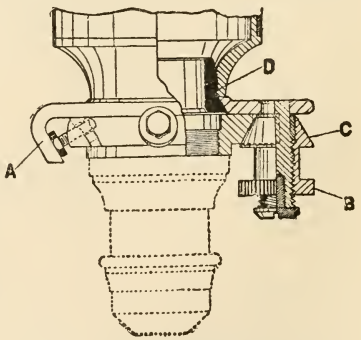


FIG. 8.—No. 3280, Sloan Object Glass Changer.

Loose fittings (Fig. 9) are supplied, one of which is screwed on to each object glass.

Each fitting has a bevelled gap which fits loosely over the bevelled nut (C) of the adapter and swings round into position when a turn of the milled head (B) forces the fitting against the sloping projection (A) and holds it firmly in position. Each

adapter has screwed studs with clamping screws, which form the stops in both directions when the object glass is in the correct position. These can be adjusted by means of a spanner supplied for the purpose, so that each lens can be centred with an accuracy that is never possible with a revolving nosepiece, because the error of each individual object glass cannot be compensated with the latter.

The construction of this apparatus is so simple and rigid, having no slides to wear loose, that it remains in adjustment permanently.

The total extra length of the microscope body caused by its use is 10 mm., and the drawtube should be set at 150 mm. to obtain the standard tube length.

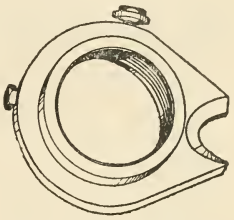


Fig. 9.—No. 3281, Fitting of Sloan Object Glass Changer.

A box is supplied to carry object glasses with fittings screwed on ready for use, held against dust-tight pads.

Illumination.

The illumination of an object seen with a microscope is of almost as much importance as the quality of the lenses. It is interesting to find that the methods worked out by those who were enthusiastic in the use of the microscope as an enjoyment, and to a great extent as an amusement, have been one by one adopted by the more serious scientific worker who has sometimes been ready to consider the time spent on the pure manipulation of the instrument to be of little value. The proper use of the substage condenser to regulate the light in viewing transparent objects is now acknowledged to be of first importance for correct observation. Dark-ground illumination, which has been considered by some to be only useful to show in an attractive manner what could be seen equally well by direct light, has proved to be of paramount importance for the study of living bacteria and colloid particles. The methods devised for illuminating opaque objects have formed the basis for the observation of metallurgical specimens, and the much-criticised study of the markings of diatoms and insects' scales has proved to be of the greatest value in enabling the images seen by the microscope to be correctly interpreted. A bad lens can never be made to give a perfect image, but a good lens will only give the best image when the illumination is satisfactory. Most objects seen with the naked eye only require that a sufficiently powerful light should fall upon them. They reflect back the light that they receive, or the greater portion of it, in all directions. It is not of importance where the light which illuminates them comes from, although occasionally, when the light falls upon them from one side only, such deep shadows may be formed that it is difficult to recognise the true appearance.

Vision of natural objects.

The same holds true of opaque objects examined with the microscope, but the greater number of microscope specimens are either transparent or semi-transparent, and must be viewed by sending a beam of light through them from behind. This beam then passes through the microscope into the eye. Natural objects are seldom viewed in this manner, but in order to examine the water mark of paper or a photographic transparency, they must be held between a strong light and the eye, and the ability to see the pattern of the water mark or the view in the transparency depends on certain portions of the light being blocked out which would otherwise enter the eye. In the black portion the whole light is stopped, in others only a portion is absorbed, and thus a complete range of tone in the picture may be obtained. This is the method by which semi-transparent objects are seen with the microscope.

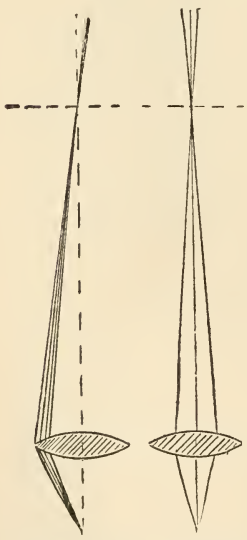
The conditions are not the same as ordinary vision, and the direction and character of the beam of light used to illuminate them are a matter of great importance.

The mirror.

The mirror of the microscope (F, Fig. 1) is used to direct a beam of light from some source of illumination through the object into the microscope. The mirror swings in gimbals and can be moved in all directions. It has on one side a flat, silvered surface which gives a plane reflection, and on the other a concave surface which concentrates a more powerful beam upon a small area of the object.

Direction of the light.

The direction of the light should be such that it shines directly along the line that passes through the centre of the microscope—the line that is known as the optic axis. If the light comes from the side it passes obliquely through the object, and even if it does not give an erroneous appearance it prevents a clear image being formed. To illustrate the effect on the object, one should examine the appearance of a fairly thick piece of wood which has fine holes drilled in it: light from one side would not pass through and would not reach the eye. The holes will not be visible unless the light is passing through them centrally. The effect of an oblique beam of light as it passes through the microscope lenses is shown in Fig. 10.



Oblique light. Direct light.

Fig. 10.

The left-hand diagram in Fig. 10 shows the object glass transmitting oblique light only. The light which actually forms

the image is a fine bundle thrown to the edge of the object glass, so that the object glass acts as if it had only a pinhole aperture at one side, and is consequently no better for depicting detail than the early pinhole lenses which were made before the modern achromatic microscope was discovered.

This diagram also shows how the direction of the light can be immediately recognised by focussing the microscope. The only light producing the primary picture is shown in the left-hand diagram of Fig. 10. It is on the right or the left of the axis, according to whether it is above or below the true focus. Therefore, by putting the object in and out of focus with the focussing adjustment, the direction of the light can be observed. When the light which illuminates the object is oblique instead of being truly central, the object will not only become indistinct on either side of the focus, but will appear to move from side to side; whereas if the light is truly central, the object will become less distinct on either side of the focus, but will not alter its position.

The mirror can always be adjusted until the object remains stationary as the microscope is being focussed, and the centring of the light is thus assured.

Below the stage of the microscope an iris diaphragm (K, Fig. 1) is fitted, and if this is shut down to a small aperture the light will not pass through the microscope at all if the light is very far away from the axis, though this is not in itself sufficient to make the final adjustment.

Nature of illumination.

The nature of the illumination may be varied according to whether it is parallel, divergent, or convergent. If the flat side of the mirror be used and the source of light is at a considerable distance, a beam of nearly parallel light is obtained (*a*, Fig. 11). If the source of illumination is very close, a divergent beam is obtained (*c*, Fig. 11). If the concave mirror is used, it will be a slightly convergent beam (*b*, Fig. 11). By means of a substage condenser (J, Fig. 1) with an iris diaphragm below it—described later—the light can be rendered still more convergent and can be regulated with accuracy. As the light which enters the condenser at its margin emerges as the outer portion of the cone, the effect of reducing the aperture of the diaphragm of the condenser is not only to reduce the amount of illumination, but to alter its character by reducing the size of the cone of emergent light. Thus with a very small aperture an almost parallel beam of light can be obtained, and by opening the iris diaphragm a more and more highly convergent cone of light may be used (see p. 27).

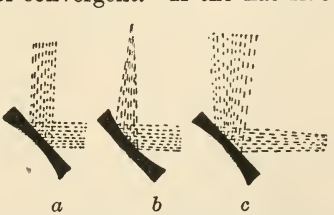


FIG. 11.—Mirror reflecting parallel, convergent, or divergent light.

Illumination for transparent objects.

As regards the best kind of illumination for transparent objects, the light may be a nearly parallel beam from the flat mirror, or a slightly divergent beam from the flat mirror used with a lamp near the mirror. The light from a lamp may be rendered nearly parallel by placing a bull's-eye condenser close to the lamp. To find the correct position for the bull's-eye to give parallel light, an image of the flame or filament of the lamp should be observed on a distant wall and the bull's-eye moved till the lamp or filament is in sharp focus on the wall. The light is then approximately parallel, and the microscope should be so placed that the mirror is in the beam of light about 8 or 10 inches away from the lamp.

The light may be made slightly convergent if the bull's-eye be arranged to give parallel light, but the concave instead of the flat mirror be made use of.

The light may be condensed by a substage condenser, which not only increases the brilliancy of the illumination, but also gives a strongly convergent beam of light which may be modified to any extent by the use of the iris diaphragm and stops, as described more fully under the description of substage condensers.

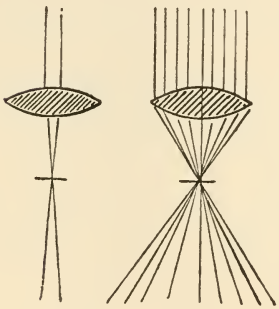


FIG. 12.

The question as to whether the best results will be obtained by parallel, divergent, or convergent illumination, depends to a great extent on the nature of the object. When light shines through certain kinds of objects it is distributed or scattered in all directions. A cut-glass lamp-shade breaks up the light that falls upon it and scatters it all round; the same thing occurs to a lesser extent in the case of a botanical or histological section of tissue when each cell or irregularity acts like a facet of a cut-glass lamp-shade. In this case, whatever the nature of the illumination, there is a sufficiently scattered light to fill the aperture of the object glass, and the general structure of the tissue will be accurately depicted. This, however, does not apply to all kinds of objects. Some do not scatter light, and the question as to whether the aperture of the object glass is filled with light depends on the nature of the illuminating beam. If an object which does not scatter light is illuminated as shown in Fig. 12 (*a*), the object glass might just as well have nothing but a pinhole aperture; and to make use of the aperture a convergent cone of light must be thrown upon the object, as shown in Fig. 12 (*b*).

Scattering of light by object.

All small objects spread the light slightly by diffraction, though in the case of a single dark object on a white field, the

amount of such spreading is relatively small and need not be considered. If the object is a regular periodic structure, like a series of dots and lines, the spreading due to this cause may be very considerable, and such an object may not require so large a beam to use the full angle of the object glass.

This is very noticeable in the case of the fine periodic structure of diatoms, where the structure may often be shown when the illuminating cone of light is considerably less than that required to fill the whole of the aperture of the microscope. In such cases it will be observed, if the eyepiece of the microscope is removed, that the central direct beam illuminates the central portion of the back lens of the object glass, but the rest of the lens may be illuminated almost as strongly by the large amount of diffracted light scattered by the periodic structure of the diatom.

For the use of the microscope with any but the lowest magnifying powers, a substage condenser should be used in order that the nature of the illumination may be completely varied at will.

CHAPTER II

ILLUMINATING APPARATUS AND SOURCES OF ILLUMINATION

A most important part of the microscope has now to be considered, namely, the substage condenser, which is essential with all higher powers to converge a beam of light upon the object in order to illuminate it brilliantly and to vary the character of the illumination.

Substage condensers.

There are three different kinds of substage condensers. The simple so-called Abbe condenser consists of two lenses with an iris diaphragm close behind the back lens and a tray below for the insertion of patch-stops or colour filters, as shown in Fig. 13. It was in use under various names long before the time of Abbe, who, however, popularised it in a particular form of mounting. It does not focus the rays correctly to one spot (see Fig. 14),

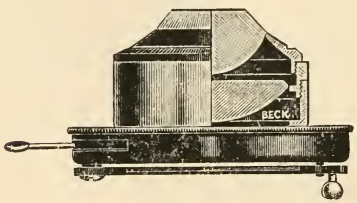


Fig. 13.—No. 3286, Abbe Condenser.

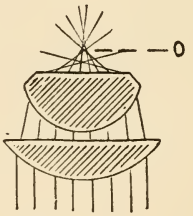


Fig. 14.

the oblique rays coming to a nearer focus than the more direct, and does not form a definite image of the source of illumination due to the uncorrected lenses of which it is constructed. It has an aperture of 1 N.A.—that is to say, it will give 180° in air, the maximum aperture obtainable with a dry condenser. A large beam of light from the mirror thrown upon the back lens is concentrated upon a small area (O). This area is illuminated by an imperfect image of the source of light. The condenser fits into the substage of the microscope by which it can be moved up and down, or "focussed," or can be moved laterally, or "centred," until the illuminated area (O) coincides with the object being examined. The object is by this means brilliantly illuminated. A powerful illumination is often required to overcome the loss of light due

to the large magnification obtained with high-power lenses; but this is not the only advantage gained by the use of a condenser, as illumination might be increased by other means—for instance, by bringing a source of light closer to the object. A substage condenser receiving an approximately parallel bundle of light from the mirror of the microscope converts it into a wide angle cone of light. When this light is centred and focussed, the object is illuminated by light falling upon it in all directions.

Achromatic condenser.

The achromatic condenser (Fig. 15) has the same aperture as the Abbe condenser 1 N.A., but it is corrected almost as carefully as a microscope object glass, so that the rays come to exact points, and a very perfect image of the source of illumination is formed in the plane of the object, much reduced in size. It is provided also with an iris diaphragm and a tray for patch-stops and filters. Fig. 16 shows a beam of light (A, B, C, D, E, F) passing through this condenser to the central point of the object at O. The rays A, F, which are at the margin of the beam of light as it enters, emerge as the most oblique rays falling upon the object O, and the rays C, D, which enter near the centre of the condenser, emerge nearly parallel. Thus, if the iris diaphragm which is placed below the condenser is gradually closed, it excludes more and more of the oblique rays. Fig. 16 shows a large solid cone of light of great angle converged upon the object, the iris diaphragm being fully open. Fig. 17 shows a small-angled cone transmitted by the same condenser, the iris diaphragm being partially closed. Fig. 18 shows the same condenser in which the iris diaphragm is fully open and an opaque patch or stop is placed below the condenser so that the object is being

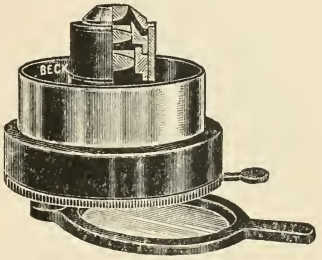


Fig. 15.—No. 3288, Achromatic Condenser.

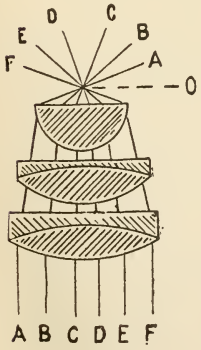


Fig. 16.

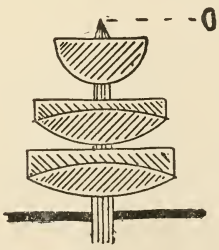


Fig. 17.

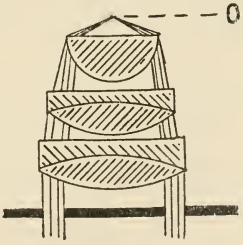


Fig. 18.

illuminated by a hollow cone. Stops or patch-stops with apertures of different shapes, or in different positions below the condenser, used in combination with the iris diaphragm, regulate the illumination so that light in any direction may be passed through the object.

Immersion achromatic condenser.

The dry and immersion achromatic condenser is of even higher quality than the achromatic condenser, being equal in its corrections to a microscope object glass, and has an aperture of 1·3 N.A., so that it can, if used in immersion contact with the under-surface of the slide, fill the whole aperture of an oil-immersion lens with light.

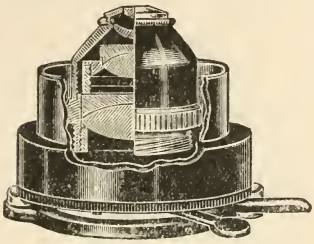


Fig. 19.—No. 3291, Dry and Immersion Condenser.

Use of a substage condenser.

For transparent objects with object glasses as low in power as a 1½-inch (32-mm.) a condenser is not required. The aperture of such a low-power lens is small, and the angle obtained by the use of a concave mirror is usually sufficient to make the best use of this lens.

The same applies to some extent to the 2/3-inch (16-mm.) object glass, but as this lens is so frequently used as a finder for a high-power, it is not always convenient to rapidly remove the condenser, and it is customary to use the condenser, but to put it somewhat out of focus in order to fill the whole field with an even illumination. A condenser should always be used with the 1/3-inch (8-mm.), 1/6-inch (4-mm.), 1/8-inch (3-mm.), or 1/12-inch (2-mm.) object glasses.

A substage condenser is only corrected for light which is parallel or slightly divergent; therefore the flat mirror should be used. The concave mirror giving convergent light is quite unsuitable for use with a condenser.

Daylight as a source of light is not recommended with a condenser, as the finest detail cannot be shown by its means. For ordinary microscopic examination of not too critical a nature, daylight is satisfactory, but even then the more delicate details may escape notice.

Assuming that the source of light is a paraffin lamp with a flat wick, or other small source of illumination, the condenser must first be focussed and centred.

To focus a substage condenser.

In order to focus the condenser, sufficient light must be thrown through the object to render it visible, and the object glass must be focussed upon the object. The iris diaphragm of the condenser should then be shut down to about one-quarter its size, and it should be focussed up and down until an image of the flame of the lamp is seen sharply in focus at the same time as that of the

object; the mirror will require to be adjusted in order to direct the light through the condenser. If the lamp be turned round so that the edge of the flame is opposite the mirror, it makes an easier object to focus, and its image will appear as a slit across the field of view. When focussed the lamp may be turned round, with the flat side of the flame facing the mirror, thus illuminating the whole field. It is found in practice that the best resolution is obtained when the source of light is almost, but not quite, in focus.

To centre a substage condenser.

The accuracy of centring of the simple Abbe condenser is not important. The image that it gives is not accurate, and it is generally sufficient to move the mirror slightly till the image of the object does not move from side to side, while the body of the microscope is being focussed up and down in a similar manner to that described on page 22 for setting the mirror when used alone. Microscopes fitted with this condenser are frequently not provided with a centring adjustment to the substage.

When using the achromatic or immersion condenser centring is a matter of importance. The iris diaphragm is placed in a position at such a distance below the condenser lenses that if the condenser be moved downwards the source of light will be put out of focus and an image of the small aperture in the iris diaphragm can be sharply focussed. When doing this the iris diaphragm should be closed to its smallest aperture, so that the image is of a sufficiently small size to be seen in the field of view. The condenser may then be moved by the centring screws until the image of the diaphragm is in the centre of the field of view. If the image of the small aperture is so far out of centre that it is not in the field, the aperture can be enlarged until its edge begins to appear. When the condenser has been thus centred it should be moved upwards till the image of the lamp is again in focus on the object, and the mirror readjusted if the light is not in the centre of the field.

The achromatic condenser is now in the best position for use with a 1/3-inch (8-mm.), 1/6-inch (4-mm.), or 1/12-inch (2-mm.) object glass, though slightly better resolution is obtained if the source of light is a little out of focus. If it is required to use a 2/3-inch (16-mm.) object glass, the condenser can be focussed down to give an evenly illuminated field, being brought back into focus when a higher power is used.

Effect of opening and closing iris diaphragm of condenser.

The substage condenser having been focussed and centred, the eyepiece of the microscope should be removed, and the effect of opening and closing the iris diaphragm be observed by looking down the tube of the microscope. This effect is best observed when an object glass with a fairly large aperture such as 1/6-inch (4-mm.) is used. When the iris diaphragm is fully open the back lens of the object glass will be completely filled with

light appearing as a uniform circular disc; closing the diaphragm will at first not make any change in the appearance, because the condenser is coverging upon the object a beam of light of greater angle than can be collected by the object glass, and it will receive the full illumination until the light from the condenser becomes smaller in angle than the aperture of the object glass. If the diaphragm be now closed to its fullest extent, the back lens of the object glass shows a small spot of brilliant light in the centre; and as the aperture of the iris diaphragm is slowly opened, the spot of light slowly increases in size until the whole of the back lens of the object glass is completely filled with uniform light. As soon as this is done the whole of the aperture of the lens is receiving direct light from the condenser shining through the object as shown in Fig. 16.

Effect of focussing a substage condenser.

While the microscope is in this condition, the effect on the appearance of the back lens of the object glass, which is produced by putting the condenser in and out of focus, should be observed. The iris diaphragm being open to the full extent, it will be found that unless the condenser is in correct focus the whole area of the back lens will not be equally filled with light, and from the appearance so observed it can be realised why an uncorrected condenser like the Abbe condenser cannot readily be made to fill the whole area of the object glass with uniform light, the reason being that the light of different obliquity is brought to a focus at different positions. It may be that only one ring of light at the edge of the object glass, or a small area in the centre, or a combination of both, is being illuminated.

Best aperture of illuminating cone.

The importance of the character of the illumination has been referred to, and the question arises as to what aperture cone of light it is best to use. A well-corrected substage condenser centred and in focus gives the means of completely controlling this, and from what has so far been said it might be supposed that the full aperture of the object glass should be always illuminated; this is not necessarily the case, further research is required before definite rules can be laid down to meet all conditions. For the best resolution the diaphragm in the condenser should never be opened to admit a larger angle of light than that of the object glass, or "glare" may produce a misty appearance which will destroy the crispness of the image.

This can be avoided by reducing the size of the diaphragm until the aperture just becomes visible at the edge of the back lens of the object glass. To what extent the angle of light admitted by the condenser should be smaller than the aperture of the object glass depends upon the nature of the object. Full resolution will only be obtained if the whole aperture of the object glass is transmitting light, for reasons previously explained; and if the light from the condenser were not filling the aperture of the object glass, and there were no object on the stage, the

aperture condition would not be fulfilled until the iris diaphragm was open to the desired amount to fill the back lens of the object glass; but the object itself always has some, and often a very great, power of scattering light. Even when the condenser diaphragm is cut down to a minute aperture, such an object as a diatom or a podura scale scatters so much light that on looking at the back of the object glass it is almost as bright over its whole surface as at the spot where the direct light passes through, and the image is formed by the scattered quite as much as by the direct light.

Resolution by light scattered by object.

The markings of the podura scale form a good illustration of this point. The scales of this small insect appear to have markings somewhat like small quills. If the aperture of the condenser is reduced so as to send direct light through only a comparatively small fraction of the object glass, the best image of these quills is formed somewhat as Fig. 20 (A). If the diaphragm be opened beyond a certain amount the clearness of this image is reduced. If a diaphragm is inserted at the back of the object glass to cut off all the scattered light, and only let the direct light from the condenser through, the image will be absolutely fuzzy and indistinct, somewhat as Fig. 20 (B), showing that in the delineation of this object the light scattered by the object is doing the work of resolution, and that it is not done so well if the full cone of light is passed through the object by the condenser. The same applies to a lesser extent to some diatom structure, though in this case the finest structure is always best shown by a large cone of light from the condenser.

FIG. 20.

The tubercle bacillus embedded in tissue is extremely difficult to see unless a large cone of light is used, and in the early days of its discovery its existence in the tissues themselves was doubted by some of those who were not in the habit of using a condenser to its best advantage. Some delicate semi-transparent objects are quite invisible when a large cone of light is used, but can be seen with a pinhole aperture in the condenser. It should be understood, however, that appearances created by the use of very small apertures may be incorrect representations of the correct structure. In the case of the podura scale and the structure of diatoms, the nature of the actual structure is not definitely known, and it is not certain that the images obtained of these apparently well-marked structures are even approximately correct. Observers have frequently claimed the discovery of delicate envelopes around bacilli and micrococci which a skilful microscopist can at once refer to the result of incorrect illumination. It is generally best to use the largest aperture in the condenser that does not produce indistinctness, for the image is more likely to be a correct representation; and it is well to try

different apertures when it is required to observe very fine structure.

Variation of light intensity when iris diaphragm of condenser is altered.

There is a difficulty in making use of different apertures because the light varies so greatly by the change in the aperture of the condenser, that the variation in intensity becomes a serious inconvenience. The observer should never be tempted to overdo the brilliancy of the illumination; several pieces of ground glass should be at hand to place between the lamp and the mirror to modify the light as the condenser is opened up.

Double wedge light moderator.

The most satisfactory appliance for critical work is an adjustable pair of neutral tint glass wedges mounted on a stand which can be placed between the light and the mirror of the microscope to vary the intensity of the light at will. The apparatus consists of a frame which carries two neutral glass wedges which slide in fittings and are connected together so that they move over one another in opposite directions by sliding a knob. The total thickness of the neutral tint glass is varied and the brilliancy of the illumination increased or decreased within very considerable limits. The frame is attached by means of a clamp to a rod fixed to a strong stand. Its height from the table may be varied from 2 inches to 8 inches, and two slides are provided in front of the wedges for the reception of colour filters or ground glass.

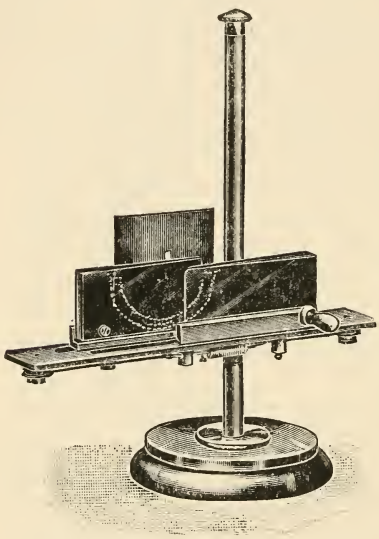


Fig. 21.—No. 3328, Double Wedge Moderator.

As the illumination is increased by opening the diaphragm of the condenser, it can be reduced by thickening the neutral tint layer of glass by sliding the two wedges over each other. This apparatus can be provided with wedges of different intensities according to the strength of the illuminant with which it is to be used.

The use of a small bundle of oblique light directed upon the object at a particular angle has been studied in connection with the delineation of line structure. It is accomplished by cutting a small hole in an opaque sheet of card, metal, or celluloid, and placing this aperture in different positions under the condenser,

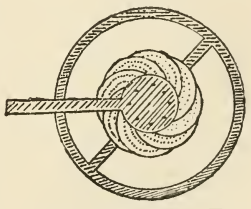
so that one or more selected beams of oblique light may be used to illuminate the object. An experiment with finely ruled parallel lines shows that if a small oblique beam of light is used to illuminate them at right angles to their length, finer lines can be distinguished than with direct light; but it is doubtful whether this method is of any advantage for ordinary objects, and it is liable to give rise to quite erroneous impressions of structure.

Dark-ground illumination is obtained by throwing light upon the object in such a manner that the object is illuminated, but that none of the light enters the microscope except that reflected by the object itself.

The illuminator must be capable of throwing light upon the object at a greater angle than can be received by the object glass in use. The illuminator must have a larger aperture than the object glass. Dark-ground illumination with a substage condenser in which the object is illuminated by light that is so oblique that it cannot enter the object glass is accomplished by placing a glass with a central black patch below the condenser and by opening the iris diaphragm to its full extent, as shown in Fig. 18, page 27. With the Abbe form of condenser this method is useful for low powers—1½-inch (32-mm.) and 2/3-inch (16-mm.)—but is not sufficiently corrected to cut off the central light with the accuracy required for a high power. It will perform fairly well with a 1/3-inch (8 mm.) achromatic, which has an aperture of ·5 N.A., but not for lenses with a larger aperture. With the achromatic or immersion condenser, dark-ground illumination can with care be used with a 1/6-inch (4-mm.) object glass, but it is better to use a special high-power illuminator described later for the 1/6-inch (4-mm.), 1/8-inch (3-mm.), and the 1/12-inch (2-mm.) object glass. This is partly because the high-power illuminator is of shorter focal length and gives more brilliant illumination, and partly because the stop of a substage condenser is some distance below the lenses and allows some light to spread round the stop employed. It does not produce so black a background.

Dark-ground illumination with substage condenser.

For dark-ground illumination with a condenser, an adjustable stop invented by Mr. Traviss (Fig. 22), on the principle of a reversed iris diaphragm, is a very convenient appliance. By moving the handle the size of the central patch is enlarged or diminished.



Adjustable patch-spot.

Fig. 22.—No. 3284, Traviss Patch-stop.

The high-power dark-ground illuminator is a reflecting device by means of which a very small image of the source of illumination is focussed upon the object, and this image is formed by rays of light which fall upon the object at a very oblique angle. Fig. 23

High-power dark-ground illuminator.

shows the optical portion of this illuminator. The light from the mirror being thrown upon the under-surface of the glass reflector, the light is reflected by two curved surfaces so that a ring of light is focussed to a point upon the object at a very oblique angle, as shown by the white portion of the diagram. The whole of this light is so oblique that it will all be totally reflected inside the glass and will not emerge from the illuminator unless the latter is brought into immersion contact with the under-surface of the slide by placing a drop of cedar-wood oil between the top of the illuminator and the slide. It must be used in immersion contact with the slide in the same way that an oil-immersion object glass is used in immersion contact with the cover glass. With this illuminator any dry lens or an immersion lens with an aperture of less than 1 N.A. can be used, and no direct light, but only that reflected by the object, enters the microscope (see Fig. 24). A special oil-immersion 1/8-inch (3-mm.) focus, with an aperture of ·95 N.A., is made for work with this illuminator; or an immersion lens with a larger aperture can be used if it be stopped down by means of a small diaphragm placed behind the back lens of the object glass.

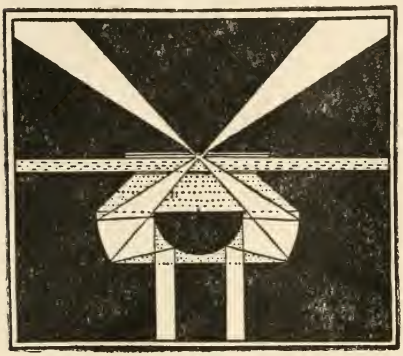


Fig. 23.—No. 3295, High-power Dark-ground Illuminator.

Use of oil-immersion object glasses with dark ground.

In the latter case the object glass must be stopped down to a considerably smaller aperture than 1 N.A., because the stop cannot be placed in the best position, which is between the lenses themselves, and with a stop behind the back lens a certain amount of direct light is not properly excluded by a stop of the theoretical size, because it is not in the correct position.

There is a peculiarity in dark-ground illumination. The object must be exactly at the crossing point of the beams of light—that is, in its focus—or it will not be illuminated at all (see Fig. 24), whereas with an ordinary condenser, even if the object is not in the exact focus, it will still be illuminated, though, perhaps, not so brilliantly. The non-focussing dark-ground illuminator has no adjustment; as the front portion of the illuminator must be in immersion contact with the under-surface of the slide, it cannot be moved up and down, and therefore the slides used with this illuminator must be 1 mm. thick. Slides of this thick-

ness can be selected for examining living specimens, but mounted objects can seldom be examined.

To overcome this difficulty, R. & J. Beck, Ltd., have designed the dark-ground illuminator (Figs. 24 and 25) with a focussing adjustment. The upper lens (C) remains in immersion contact with the slide, but the reflector (D) can be moved up and down, which raises and lowers the illuminated point, enabling any slide of from $\frac{1}{2}$ mm. to $1\frac{1}{2}$ mm. thickness to be used.

Focussing dark-ground illuminator.

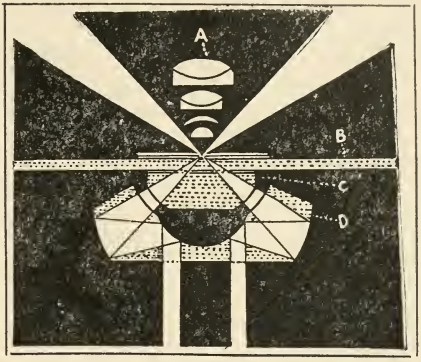


Fig. 24.—No. 3294, Focussing Dark-ground Illuminator.

A convenient means of setting the focus for a particular slide is arranged for in the mount of the illuminator. Fig. 25 shows the focussing illuminator mounted for use on the Standard London Microscope. Turning the lever (C), which projects from the lower portion of the mount, moves the focussing lens (D, Fig. 24); in doing this it also moves the pin (A, Fig. 25) up and down, and alters its distance from a flange (B, Fig. 25) on the mount.

If the lever (C) is moved till this pin (A, Fig. 25) is at its farthest distance away from the ring (B, Fig. 25), the slip that is to be used may be placed between the ring (B) and the pin (A); and if the lever (C) be again moved till the pin (A) just clamps the slip, the illuminator will be approximately set to the correct focus for this thickness of slip. The final adjustment may then be made when the object is in position.

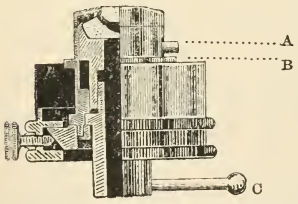


Fig. 25.—No. 3294, Focussing Dark-ground Illuminator.

The high-power dark-ground illuminator has been found specially valuable for the examination of living bacteria, rhizopods, and other transparent and unstained specimens that are difficult to see with direct light. Such objects, however, due to their transparency, reflect only a small portion of the light that falls upon them, and a strong illumination is necessary. To accomplish this the high-power illuminator is made to produce a very minute image of the source of light, so that all the light may be concentrated on a very small area, almost a point.

To centre high-power dark-ground illuminator.

It is therefore necessary that a centring adjustment should be provided, so that the illuminated point may be exactly in the field of view. If the substage of the microscope is not provided with a centring adjustment, the form of dark-ground illuminator mount which has centring screws should be used.

To centre the illuminator the following is a satisfactory method of procedure :

Remove the eyepiece and object glass from the microscope and swing out the substage. Place the eye six or eight inches above the tube of the microscope, and move the eye until the lower end of the microscope tube, where the object glass screws in, is central with the upper edge of the drawtube. Then, without moving the eye, move the mirror until the light appears in the centre of these apertures. Swing in the substage with the dark-ground illuminator without moving the microscope or the mirror, place a drop of cedar-wood oil upon the upper surface of the illuminator, put the object to be examined on the stage, and move the substage up till the illuminator is in immersion contact with the slip. This having been done, put a low-power object glass, say 2/3-inch, into the microscope, use a low-power eyepiece, and focus the slide. There will be sufficient dirt or particles on the slide to show the small illuminated point, which will probably not be in the centre of the field. By means of the centring screws of the substage or the illuminator mount, this illuminated patch may be brought into the centre of the field, and the 2/3-inch object glass may then be replaced by the object glass which it is desired to use. A further slight adjustment may be made for the new object glass if necessary, after which the centring screws should not be touched, but slight alterations should be made by altering the position of the mirror. Until the centring of the illuminator has been completed, the position of the lamp, the microscope, or the mirror, should not be altered.

To focus high-power dark-ground illuminator.

Focussing, as previously mentioned, is almost impossible with the non-focussing illuminator, although a very small movement of the substage is possible without breaking the film of oil between the illuminator and the slip.

With the focussing model it is best to set the focus approximately by the pin on the mount, as described, but a small movement of the adjusting lever while the object is being observed is particularly useful in obtaining the best result.

If the illuminator is out of focus, a dark circular patch will appear in the centre of the field surrounded by a bright ring; when focussed, the central dark patch disappears.

Objects mounted dry cannot be examined by this illuminator. They must be in some fluid or medium, as no light will reach the object if there is any layer of air between it and the illuminator.

It is important to see that the slips and cover glasses are thoroughly clean and that there are no air bubbles in the oil or

the fluid containing the object, as reflections from dirt or bubbles may cause a glare that destroys the black background against which the illuminated objects stand out.

Intensity of light.

A strong source of light for use with this illuminator is essential. It is referred to under the heading of "Illuminants." If the light is of only moderate intensity, a bull's-eye condenser should be used. It should be placed at such a distance that an image of the lamp is formed in the centre and on the surface of the mirror. The correct position is best ascertained by holding a white card on the mirror while the bull's-eye is adjusted between the lamp and the mirror.

When a colour filter is used, a stronger light than would otherwise be required should be available. The light, however, must not be too strong, for although a weak light will not illuminate such transparent structures as bacteria sufficiently to render them visible, too strong a light shows up certain diffraction images and destroys definition.

It is, therefore, necessary to reduce the illumination to just such an extent that these diffraction effects are not aggressively apparent.

A very brilliant source of illumination, such as an electric "Pointolite" lamp, gives more light than is required, except for use with colour filters; but used in combination with the adjustable neutral tint wedges (p. 32), gives every intensity of illumination that is required for this and all other classes of microscopic work.

Resolution easier with dark-ground illumination.

Those who have not used this form of illumination cannot realise the large amount of extra structure that can be recognised by its means in certain classes of objects. The spines or pseudopodia of Coscinodiscus were discovered by dark-ground illumination. Hidden structure in bacteria has been revealed, and the markings of diatoms are shown with greater brilliancy by this illuminator than by any other means. The resolution of diatoms is much easier with dark-ground illumination because it gives far greater contrast. If an object is not opaque and only appears slightly darker than the background, it is but faintly seen when viewed by transmitted light; but if it has even a small power of reflecting light it can be made to show brilliantly upon a black ground provided the illuminating source is sufficiently powerful.

Reflection of light takes place from any object that has a different refractive index or density from that of the material in which it is situated. A very small difference of density only is required to give reflection. An interesting experiment to illustrate this consists of taking two plates of glass with a layer of water between them, and flowing in from one side a few drops of a highly refracting fluid, which gradually mix with the water and raise its density above that of glass. As the fluid mixes, the density is gradually raised from point to point, and at the

position where it actually reaches exactly that of the glass an extremely fine line shows on looking at the surface obliquely, indicating that only at that exact point where the density of the fluid and the glass are absolutely the same is the grey effect produced by reflection destroyed and turned into black.

Bull's-eye condenser.

A bull's-eye lens on a stand used in conjunction with a lamp, or attached to the lamp itself, is required for the illumination of opaque objects. It is also useful for increasing the illumination with a dark-ground illuminator or for obtaining a moderately convergent beam of light in combination with the mirror when a substage condenser is not used. It may be used in connection with a substage condenser for increasing the size of the image of the source of light. This is of service when a very small luminous source of light, such as the electric "Pointolite," is employed.

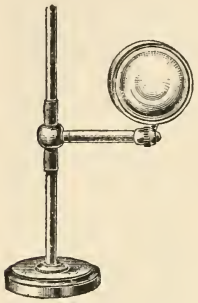


Fig. 26.—No. 3215, Bull's-eye Condenser on Stand.

On an optical bench a condenser will transfer the light source to a position nearer the microscope. Except for these purposes, it should not be employed with a good substage condenser. It does not give additional light, and it generally ruins the performance of a perfectly made condenser due to its own lack of correction.

Increase in illumination.

Its action in increasing the illumination of opaque objects can be explained by Fig. 27. A bull's-eye lens placed between the source of light (S) and the object (O) produces a small image of the source of light at (O). The upper diagram in Fig. 27 shows the lens (L) forming a somewhat reduced picture of the source of light. The lower diagram shows the distances so arranged that it is forming a much reduced image. The size of the image will depend on the relative distances from the light source to the lens and the image to the lens. In the upper diagram L O is half L S, and the image is half the size of the luminous source; in the lower diagram L O is one-quarter L S, and the image is one-quarter the size of the luminous source. The lens does not only collect a much larger amount of light than would otherwise reach the object at O, but it also compresses it into a very small size image, especially in the case of the lower diagram, and therefore it produces a very con-

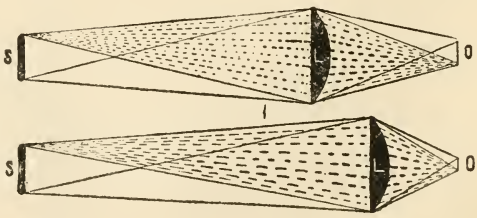


Fig. 27.

centrated and brilliant small patch of light which is made use of for the illumination of opaque objects viewed with low powers.

Condenser on lamp.

Fig. 28 shows the Beck electric lamp used with a bull's-eye condenser in this manner for condensing a powerful beam of light upon the top of an object on the stage of the microscope (see also p. 46).

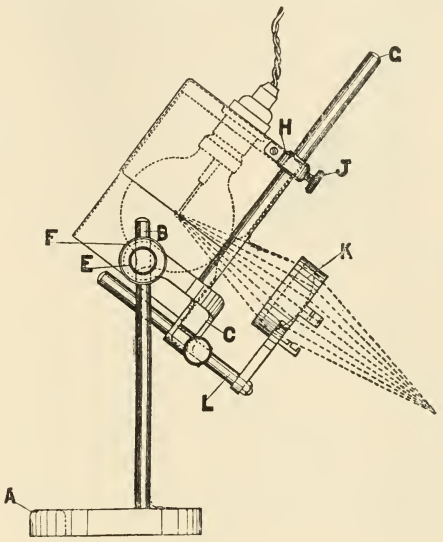


Fig. 28.—No. 3332.

A method of displaying the structure of opaque objects is sometimes adopted in which two lamps and two bull's-eye condensers are used, one of which has a blue and the other a red glass to colour the light. If these are used at different angles, difficult structure may be more easily interpreted by observing the different colours of the shadows.

Illumination of opaque objects with bull's-eye condenser.

A suitable illumination of opaque objects is required for botanical, entomological, and general work, and is of paramount importance for metallurgy. When low-power object glasses are used there is sufficient working distance (see Fig. 3) between the front of the object glass and the object to throw light in from one side by means of a bull's-eye condenser either attached to a lamp, as shown in Fig. 28, or on a separate stand (Fig. 26). When a bull's-eye is used on a separate stand there is another method of using it which is useful for even high powers. If the bull's-eye condenser is placed with its flat surface upwards, nearly parallel with the direction of the light, as in Fig. 29, the light enters the curved surface and is condensed; when it meets the flat surface it is reflected back in such a way that a very powerful narrow ribbon of light is emitted; this band is so narrow that it can be made to illuminate the object

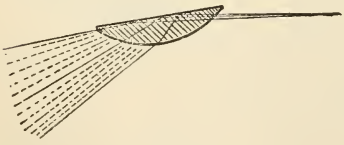


Fig. 29.

even when a moderately high power, such as a 1/6-inch (4-mm.) is used, because the band of light is sufficiently narrow to be directed through the small working distance between the object glass and the object. This method is particularly useful for the examination of alloys of metals or substances with fine laminæ, as the heavy shadows shown by such oblique illumination indicate the character of the structure.

Parabolic reflector.

Another method of illuminating opaque objects is by means of a silvered parabolic mirror, which can be attached to either a $1\frac{1}{2}$-inch (40-mm. or 32-mm.) or a 2/3-inch (16-mm. or 14-mm.) object glass. The front lens of the object glass being removed, the tubular portion of the reflector can be slid on to the cylindrical part of the object glass, which is of a standard size. This may be lightly clamped in position by the milled head and the front lens replaced. The object glass having been screwed into the microscope and focussed, the reflector, which has an adjustment up and down, should be placed so that its lower edge almost touches the object. The light should then be directed by a bull's-eye condenser in a horizontal direction parallel with the stage, so that it illuminates the whole of the reflector (Fig. 30). The reflector condenses it to a focus on the object, and a slight movement of the reflector up or down or a slight turn will give the best result. This produces a very brilliant illumination, and as the light falls upon the object from a large number of directions, the shadows produced are not, as a rule, misleading in interpreting structure.

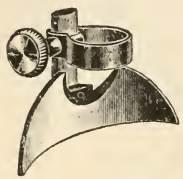


Fig. 30.—No. 3360, Parabolic Reflector.

Sorby reflector.

Mr. Sorby devised an addition to this reflector, which can be used with the $1\frac{1}{2}$-inch (32-mm. and 40-mm.) object glass, which consists of a small, flat, silvered mirror which swings in and out of the optic axis, and when it is in position it covers half the object glass. It reflects a beam of light directly downwards upon the object, which illuminates it in such a manner that no shadows are produced.

Glass reflector.

A modification of this apparatus is also used for metallurgy in which a thin transparent plate of glass is placed at 45° between a low-power object glass and the object (see Fig. 31). This has the advantage that it does not reduce the aperture of the object glass. It can be used with either a $1\frac{1}{2}$-inch (40-mm. or 32-mm.) or a 2/3-inch (16-mm.) object glass.

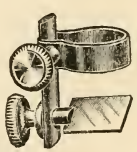


Fig. 31. — No. 3362, Thin Glass Reflector.

Vertical illuminator.

For the illumination of opaque objects viewed with high powers, a system was first invented by Mr. Richard Beck in which a thin glass disc was placed behind the object glass, and a beam

of light reflected through the object glass itself upon the object.

This illuminator is generally known as a vertical illuminator. It is screwed into the nosepiece of the microscope, and the object glass screwed into the illuminator mount. The body of the microscope is then racked into the position where the object glass is approximately in focus. The illuminator, which can be turned round, should be rotated until the two apertures in the mount are pointing one to each side, while the milled head, which carries the thin glass reflector, is at the front of the instrument. A lamp is now set up on one side, preferably the left-hand, at the height of the apertures in the illuminator, so that light will shine through the two apertures upon a card held on the right-hand side. A bull's-eye condenser may now be placed in front of the lamp, and the beam of light concentrated by this means. The milled head, which carries the thin glass reflector, should be turned round until the light is reflected downwards through the object glass upon the object. The milled head has engraved on it a line parallel with the reflector, and this enables the reflector to be set to approximately the correct angle (45°) before commencing work. The microscope can now be accurately focussed, and a slight alteration of the position of the lamp or the reflector will throw the light in one direction or the other.

Use of vertical illuminator.

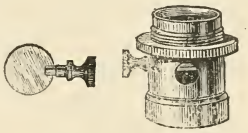


Fig. 32.—No. 3363.

For critical work the lamp-flame or source of illumination should appear, if the object be flat, as a small sharp image on its surface. This can be effected by having the lamp, if used alone, about 6 inches away from the microscope, or, if a bull's-eye condenser is used, by adjusting the distance of the bull's-eye from the lamp.

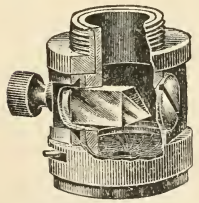


Fig. 33.—No. 3364, Prism Illuminator.

A disadvantage of this form of illumination is that the surfaces of the lenses of an object glass are convex and that a certain amount of light is reflected back into the eye by these surfaces, tending to produce a glare; but this can frequently be overcome by small adjustments in the position of the lamp or reflector so that such reflections are directed on the sides of the interior of the microscope.

Another form of this illuminator is made in which the transparent glass reflector is replaced by a small prism which occupies half the aperture of the object glass. This method reflects more light, but reduces the aperture and resolution of the object glass. The prism illuminator gives more light when used with low powers

Prism illuminator.

than the Beck illuminator, but most prefer the thin glass form for high powers, and the Sorby reflector for low-power work. As a convenient and universal illuminator for all powers where the highest resolution is not required, the prism illuminator, especially with an electric light bulb attached to it, is popular for metallurgical work. Fig. 111 (p. 120) shows this illuminator provided with a small focussing lens, a receptacle for colour filters, and a 16-candle-power electric light to suit either the 100- or 200-volt current in a metal casing.

Colour screens.

Colour screens are of use for several important purposes. They are either coloured glasses or coloured gelatine mounted between two glasses. They give greater contrast where objects being examined are stained or are naturally coloured, and give truer rendering of natural colours where artificial light is employed.

Fig. 34.

Every substage condenser should be supplied with a green glass, but a set of different coloured screens is very useful for increasing colour contrasts, both for visual and photomicrographic work. If a specimen of bacteria is stained faintly with red, the use of a green screen will make them appear almost black and much more distinct.

If a specimen is stained—

Blue,	a red	filter should be used.
Green,	a red	,, ,, ,, ,,
Red,	a green	,, ,, ,, ,,
Yellow,	a blue	,, ,, ,, ,,
Brown,	a blue	,, ,, ,, ,,
Purple,	a green	,, ,, ,, ,,
Violet,	a yellow	,, ,, ,, ,,

If the screen is too dark, and the light and shade contrast too great in consequence, fine detail in the structure may be somewhat clogged or obscured, but faintly stained or coloured specimens are rendered much more visible by the use of the correct colour filter.

Another marked advantage in the use of colour filters of green or blue is obtained by the greater power they give to an object glass of resolving fine structure.

When discussing the aperture of an object glass, the resolution was stated to be dependent on its aperture, but it is also dependent on the colour of the light. White light, when split into its component parts by, for instance, a rainbow or a prism, consists of certain pure spectrum colours—red, yellow, orange, green, blue, and violet. The resolution obtained with white light is that due to the orange-coloured portion of its component parts, because this coloured light is more powerful than any of the others that go to make it up. If a green light be used, the resolution of a microscope can be increased about 15 per cent., and if a purple be used, about 25 per cent.

A purple light, or even a very dark blue, is unpleasant to the eyes of most observers, but a bluish-green light is very restful, and is the best colour to use as regards microscope resolution.

Apochromatic object glasses are so perfectly corrected for colour that the brilliancy of their images, quite apart from resolution, will not be improved by the use of colour screens; but achromatic object glasses are always slightly, and under some conditions considerably, improved in their performance by the use of a screen which transmits a pure colour.

The green glass supplied with the substage condensers transmits a moderately pure colour, but is not so good as the special Wratten & Wainwright gelatine filters.

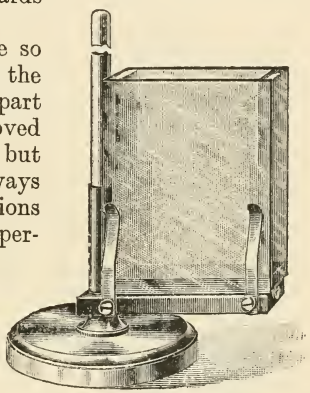


Fig. 35.—No. 3366, Monochromatic Light Trough.

A glass trough about 3/4 inch thick, filled with a nearly saturated solution of acetate of copper, makes a fairly pure blue-green screen. It is rather more transparent than a gelatine filter. Colour trough.

Various fluid screens have been used, but they are so much less convenient than the Wratten gelatine screens that they are not so frequently employed.

The best form of illuminant for the microscope depends upon many circumstances. The author is of opinion that daylight is the worst form for accurate observation, but that when it is used a screen or card with a hole in it about 2½ inches diameter should be placed in front of the mirror of the microscope about 8 or 10 inches away. This ensures a moderately parallel beam of light falling upon the mirror. A paraffin lamp with a flat flame is probably the most convenient light for general purposes, but it is not powerful enough for the use of colour screens or for high-power dark-ground illumination. The electric light of Sources of illumination.

the ordinary type is unsatisfactory unless used with a ground glass or tissue paper in front of it. A form of 1/2-watt bulb called the "Grid" is a good light, as the filaments, when looked at from the correct side, appear as a fairly large ribbon of almost homogeneous light. The "Pointolite" electric arc is extremely good for the highest power work. The incandescent gas mantle lamp is a useful illuminant, and a modification of this, heated by a methylated spirit lamp, is an excellent light for those who have not gas or electricity.

Relative intensities of different sources of illumination.

The relative intensities of a similar size small area of different illuminants are approximately according to the following table taken from Mr. A. P. Trotter's book on *Illuminating Engineering*:

Candle	$2\frac{1}{2}$
Daylight (blue sky)	2
Paraffin lamp	4 to 9
Incandescent gas mantle	50
Carbon electric filament	300
Metal electric filament	1,000
1/2-watt electric bulb	5,250
"Pointolite" electric bulb	12,000
Arc lamp	80,000 to 110,000
Direct light from the sun	800,000

From the above table it is evident why ordinary daylight is not sufficiently powerful for high-power microscope work. The sun, even in a clear climate, requires the use of a heliostat, and the arc lamp requires a special equipment. It is of great advantage to use a very intense light modified with the neutral tint wedge moderator described on page 32. The brightness of the light can then be perfectly regulated to meet requirements.

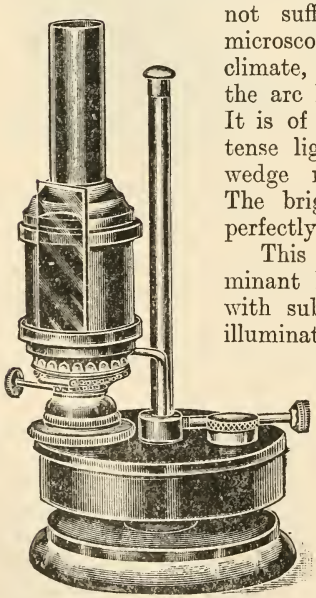


Fig. 36.—No. 3335, Paraffin Lamp.

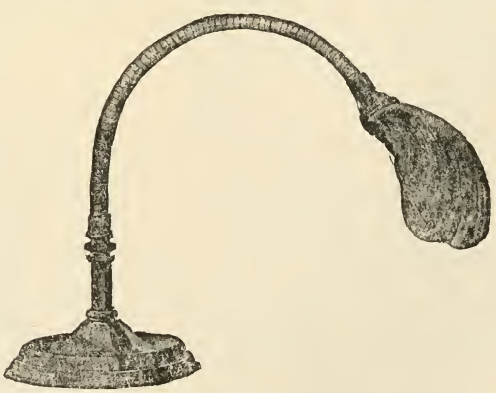
This advantage of a very powerful illuminant has been referred to in connection with substage condensers and dark-ground illuminators, but care should be exercised in its use. When direct light is being used through a condenser, it is damaging to the eyes if too strong a light is employed. A strong illuminant is necessary for high-power dark-ground or opaque illumination, but it must be modified when direct light is thrown through the object. Some colour screens require a strong light, but immediately they are removed the light should be cut down. Just enough light to show the

object readily should be used, and no more. If this precaution is taken, microscopists need have no fear of injuring their eyes, however long they work. The light should be more powerful than is required for general purposes, it should be powerful enough for dark-ground illumination and to allow of the use of colour filters.

Fig. 36 shows a good form of paraffin lamp for microscopic work. It has a single flat wick 5/8 inch wide. The burner has a revolving motion and may be used with its edge facing the mirror to give a strong illumination, and with the flat surface facing the mirror for a softer light. It has a means of raising and lowering it from the table to enable it to be used for illuminating opaque objects with a bull's-eye condenser or parabolic reflector, or for setting it to the correct height for using the vertical illuminator described on page 41. Paraffin lamp.

The reservoir and burner are carried on a support which passes through the centre of the reservoir so that the weight is well balanced over the centre of the stand. The lamp glass is simply a 3 × 1-inch microscope slip carried in a thin metal chimney. The burner is insulated from the reservoir by a fibre ring, which is always cool enough to touch for turning the burner round. The metal chimney can be removed and the burner hinged back for trimming the wick. The reservoir has a large screw stopper for filling. A bull's-eye condenser on a separate stand may be used in combination with this lamp for illuminating opaque objects or for high-power dark-ground illumination, although this lamp is not recommended for the latter purpose.

The ordinary electric incandescent lamp provided with a frosted or ground glass bulb is a handy lamp for ordinary observation, but is not sufficiently brilliant for many purposes. It is supplied on an adjustable table stand.



Electric lamp.

Fig. 37.—No. 3336, Electric Lamp on Stand.

The best equipment is the "Pointolite," or 1/2-watt "Grid" lamp, with a neutral glass double wedge, a set of colour screens, and a bull's-eye. It does everything that is required for every

class of illumination; and the Beck electric lamp is a convenient form which takes either kind of electric bulb.

Electric lamp.

The lamp has adjustment so that the beam of light can be placed at any height between 3 and 9 inches above the level of the table.

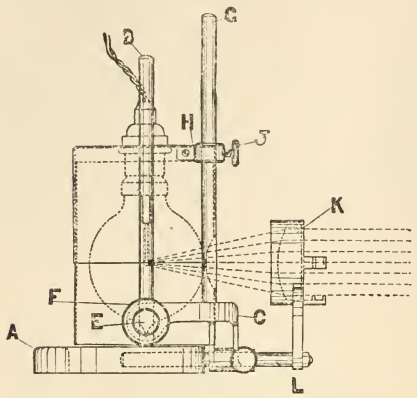


Fig. 38.—No. 3332, "Pointolite" Lamp.

The stand (A) is in the form of a heavy ring with a section cut off so that it can be placed close to the microscope.

A vertical rod (B) is fixed into this ring. On this rod a bracket (C) slides up and down and can be clamped in position at any point by a milled head (E). This bracket can also be inclined at any angle and clamped by another milled head (F). These clamps are independent of each other, and either can be used without disturbing the other adjustment.

On the bracket (C) is fixed another vertical rod (G), which, by means of the arm (H), carries the electric light bulb. This can be moved up and down the vertical rod G and fixed by a clamp screw (J) in such a position that the incandescent point of the "Pointolite" or the most luminous portion of the filament of an electric bulb can be placed in the optic axis of the bull's-eye condenser (K).

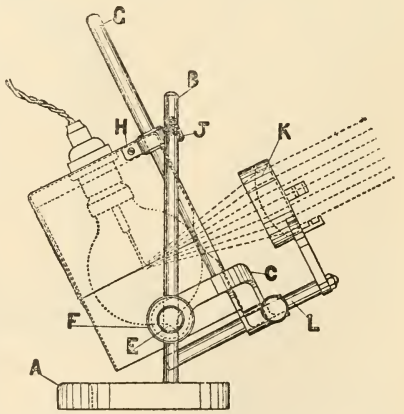


Fig. 39.—No. 3332, "Pointolite" Lamp.

The arm (H) has attached to it a thin metal cylindrical tube with a circular aperture which forms a shield to cut off stray light from the room, and when the electric bulb has been adjusted to the optic axis of the condenser, this tube can be moved up and down till the aperture in the metal casing is also opposite the condenser (K).

The condenser (K) is carried in a mount which has two slides

for colour screens or ground glass. It is supported on a rod (L) which moves backwards and forwards parallel with the optic axis for obtaining either parallel or convergent light, and can be clamped in any position.

If the condenser is not required it can be swung to one side; or if it is required to use colour screens alone, the lens of the condenser can be removed from its mount.

The illustrations show the lamp (Fig. 38) for use with the mirror of the microscope for transparent or dark-ground illumination by means of a dark-ground condenser, or for metallurgical or photomicrographic work. Fig. 39 shows it tilted for use without a mirror, or Fig. 40 shows it arranged for the illumination of opaque objects from above.

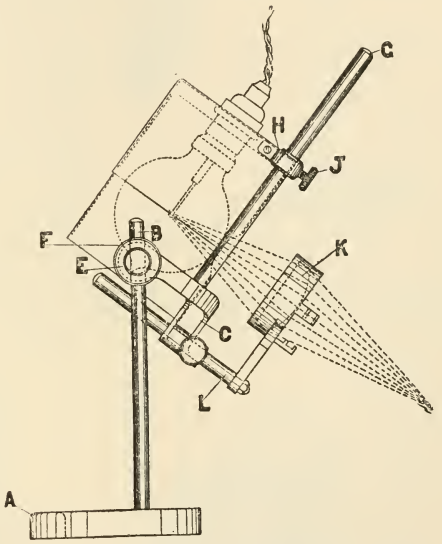


Fig. 40.—No. 3332, "Pointolite" Lamp.

The lamp is provided with a ground glass and a signal-green glass; it is completed by the addition of the Wratten & Wainwright's colour filters and the neutral glass moderator. It is provided with 12 feet of cable and an attachment for fitting it to a lamp fitting of an ordinary house supply. For use with the "Pointolite" lamp, which is an incandescent disc about the size of a small peppercorn, a direct current of any voltage from 100 to 250 volts is equally satisfactory, a variable resistance being supplied to adapt it to any current between these limits. The candle-power is 100, but as it is all concentrated in the one point it is at least twenty times as powerful as the filament lamp focussed with the condenser.

If a 100-candle-power 1/2-watt lamp or 40- or 60-candle-power metal filament lamp is used, it is suitable for either direct or alternating currents, and for a voltage from 100 to 200 volts, although a lamp suitable for the voltage must be selected.

No special wiring is required, any ordinary house current being sufficient.

Incandescent gas lamp.

An incandescent gas mantle, either of the ordinary or inverted type, makes a good light. Its only disadvantage is that it cannot be conveniently used with its image exactly in focus, because the fine mesh of the mantle does not then give a continuous surface. This light is sufficiently powerful for high-power dark-ground illumination if dark colour screens are not used.

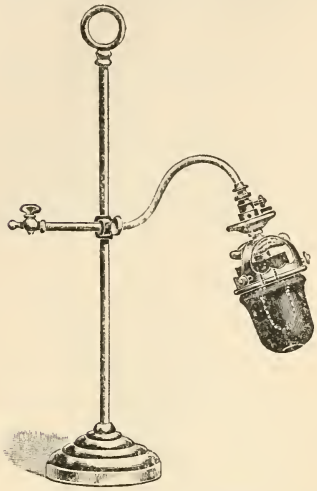


Fig. 41.—No. 3337.

Incandescent spirit lamp.

For those who have not gas or electric light, but who require a more powerful light than a paraffin lamp, an extremely useful lamp, which is quite simple to use and gives excellent results, consists of an incandescent mantle heated by a methylated spirit flame. The reservoir having been filled with spirit, the method of lighting the lamp is as follows. The cap of the reservoir must be screwed off, and the bellows attached by screwing in the nipple at the end of the tube. The bellows must be

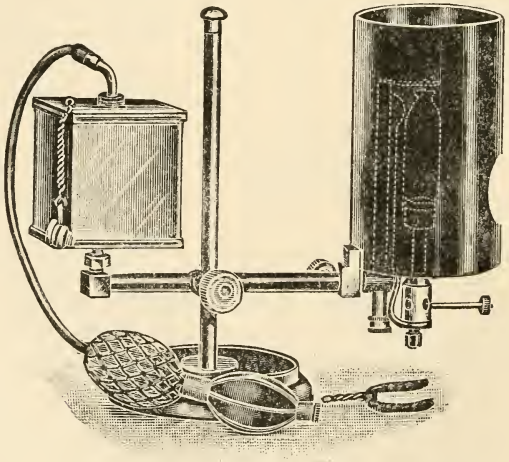


Fig. 42.—No. 3338.

squeezed till the burner is hot. The U-shaped metal piece covered with asbestos should now be soaked in spirit and placed

on the supporting tube below the burner, as shown in Fig. 42, and ignited. This will heat the burner which is inside the hanging incandescent mantle. When the asbestos-covered U-piece has almost burnt out, the bellows should be gently squeezed two or three times, which will drive the spirit from the reservoir to the burner, where it will become volatilised and burn with a steady flame. The bellows may be gently squeezed every five minutes if the light appears to be failing. The handle below the burner regulates the air supply, and should be adjusted till the best illumination is obtained.

The electric arc lamp is useful for photomicrography or projection, but is troublesome for general use.

CHAPTER III

APPARATUS FOR HOLDING SPECIMENS FOR EXAMINATION

All microscopes are provided with some means of attaching slips of glass or similar appliances to the stage, and with a means of moving them about in order to bring different portions of the slide into the optic axis of the instrument.

If the microscope is placed in a vertical position, the stage then forms a horizontal table, and the slide or slip may be allowed simply to rest on the surface, but it is difficult to move it about with a regular and even motion unless it is held in some way.

Stage clips.

The simplest holding device is a pair of springs called "stage clips" (Fig. 43), which fit into two holes in the stage and press the slide down upon its surface. They give sufficient friction to enable the slide to be pushed with the fingers with an even and steady movement.

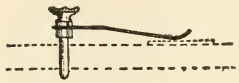


Fig. 43.—Stage Clips.

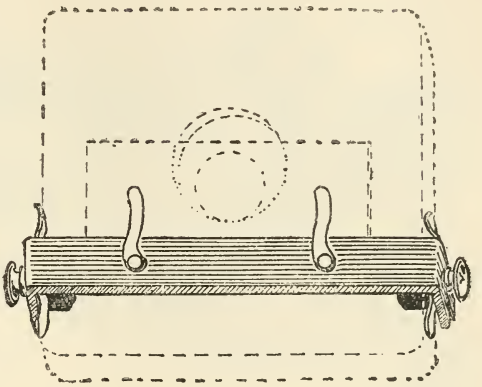
Vertical position of microscope.

The microscope should, however, not be used with its body in a vertical position unless it is necessary. It causes the observer to bend down in an unnatural manner, which is fatiguing, and is said to interfere with the proper circulation of the blood, and it allows the fluid on the surface of the eye to collect in the line of sight, interfering with perfect vision. If the microscope is inclined to a suitable angle, so that the observer can use it comfortably, most objects can be as readily examined as is the case when the instrument is in a vertical position. Even those objects which are mounted in fluid can be used in this manner, as they are almost invariably enclosed between a glass slip and a cover glass. When used in this position stage clips or some other holding device are essenital.

Sliding ledge.

A sliding ledge (Fig. 44), which fits on to the edge of a square stage and can be slid up and down, is the most convenient simple apparatus for holding a 3 × 1 slip, as a very even motion vertically can be obtained by pushing the ledge up and down, and laterally by pushing the slip to and fro along the edge of the ledge. There are two springs on the ledge which press the slip on to the stage which can, however, be turned aside if not required. A slide can be searched in this way, as the object can be raised by an

amount equal to the field of view of the microscope, and the specimens pushed all the way along. It can then be raised a similar amount and pushed back, and so on till the whole area has been searched. It is not so convenient as a mechanical stage, but makes an inexpensive substitute.



Mechanical stage.

FIG. 44.—No. 3307, Sliding Ledge.

A mechanical stage is an apparatus which holds a slide or object-holder, and by means of two racks actuated by milled heads moves it in a delicate manner in either direction. One milled head travels the object laterally, the other longitudinally. This appliance is almost essential for the delicate movement of the object when exacting work is being performed, and it has other important uses. It enables the whole of a specimen to be systematically examined over its entire surface step by step, in a manner that is impossible by hand. It is provided with scales and verniers, so that any position in a specimen can be recorded. The readings of the scale may be written upon a label on the slide, and the specimen found at any future time by setting the stage to the same reading (see page 72).

Fig. 94, page 99, shows a form of mechanical stage that is very popular. It can be attached to a microscope and removed at will, and it does not interfere with the adjustments of the substage apparatus or alter the level of the stage. It consists of a frame which holds the ends of a 3 × 1-inch slip, and moves it on the flat stage of the microscope, with which the slip is always in contact. A spring presses the slip down on to the stage and may be turned aside when not required. It has a lateral travel of $2\frac{1}{2}$ inches (65 mm.) and a vertical travel of 1 inch (25 mm.)

Rotating mechanical stage.

Fig. 45 shows a concentric rotating stage, with a mechanical stage built into its surface. In this case the slide moves longitudinally along the base-plate of the mechanical stage, but the whole base-plate moves laterally to and fro. The mechanical portion of the stage can be racked completely off the circular stage, leaving a plain stage-plate for the examination of large objects; but in this case a small readjustment of substage apparatus is required to compensate for the thickness of the travelling base-plate which

has been removed. This form has adjustable slide-holders, so that slides of any length between 2 and 4 inches can be held.

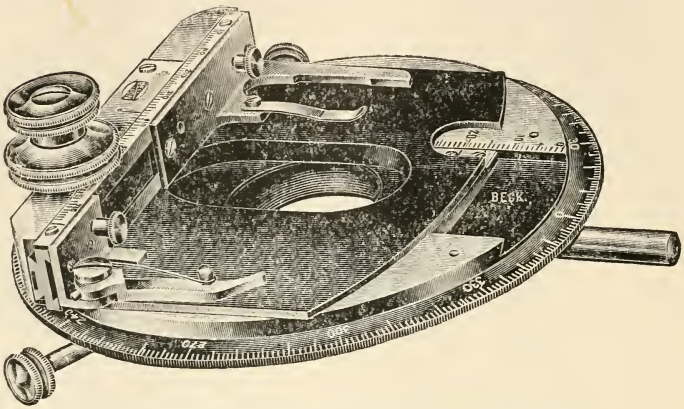


FIG. 45.—No. 3306, Rotating Mechanical Stage.

The ordinary mechanical stage is made to take only the 3-inch standard length slide. It has a lateral travel of $2\frac{1}{4}$ inches (55 mm.) and a vertical travel of 1 inch (25 mm.).

Fig. 98, page 105, shows another form of mechanical stage, in which the actuating milled heads are at the side instead of being vertically over the stage. It can also be removed from the large square stage. It has a lateral travel of 3 inches (75 mm.) and a vertical travel of $1\frac{1}{4}$ inches (30 mm.).

Centring rotating stage.

Fig. 97, page 103, shows a plain rotating stage with two stage clips and two centring screws. The centring screws are primarily intended for moving the axis of rotation so as to adjust it to the exact optic axis, but they may also be used as a means of adjusting the position of the object to a small extent in both directions. This stage has only a travel of about 1/6 inch in either direction, and cannot be used for searching a specimen or for registering positions on the slide. It forms a means of finally adjusting a specimen that has been roughly adjusted by the fingers.

A revolving stage is necessary for petrological work. It is very useful in observing opaque objects illuminated with oblique light, as the behaviour of the shadows, where the stage is rotated, assists in the interpretation of the structure. It is of great service in adjusting an object into the correct position for drawing, measuring, or photomicrography.

FIG. 46.—No. 3400, Glass Slip.

Glass slip.

Holding an object for examination under the microscope calls for various appliances, according to the nature of the object. The most universal method consists

of placing the object between a glass slip and a thin cover glass. Such glass slips are made 3 inches long and 1 inch wide, and it is only for a few special purposes that slips of any other size are used. The thickness of such slips varies from $\frac{1}{2}$ to $1\frac{1}{2}$ mm. Most forms of illuminating apparatus can be adjusted to focus through slips of such thickness, but apparatus which cannot be focussed is constructed for slips of a thickness of 1 mm., which must be specially selected.

Cover glass is a specially thin form of glass prepared for use with the microscope. It is made in squares or circles of 5/8 to 7/8 inch diameter, or can be cut to any particular size required. It is made in three thicknesses:

No. 1.	Average thickness .	·006 in.	·15 mm.
„ 2.	„ „ .	·008 „	·2 „
„ 3.	„ „ .	·01 „	·25 „

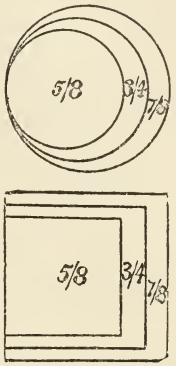


FIG. 47. — Thin Glass.

Measuring cover glass.

The thickness varies about 20 per cent. in different individual pieces, and absolute uniformity of thickness can only be obtained by selection. A screw micrometer is the most useful form of appliance for measuring cover glasses.

Cover glass can also be measured by the microscope itself, The fine adjustment milled head of a microscope is provided with a series of divisions, and the amount that the body tube of the microscope is moved by the revolution of the milled head for one division is given on page 96. A high-power dry object glass should be used, and the cover glass to be measured placed under the microscope, resting on a glass slip so that one edge of the cover glass appears near the centre of the field of view. The microscope should now be carefully focussed on to specks of dust on the upper surface of the cover glass and the position of the fine adjustment milled head observed. The milled head provided with the divisions should then be turned till the dust on the slip is in focus and the number of divisions that the milled head has moved to make the alteration noted. This number multiplied by the value of one division gives the thickness of the cover glass. It is necessary to focus particles of dust which are situated on the slip to one side of the cover glass, and not seen through it, as the optical path seen through glass is not the same as that in air.

Measuring thickness of cover glass of mounted specimens.

If it is desired to ascertain the thickness of a cover glass of a mounted specimen where the edge of the cover glass cannot be observed, the microscope may be focussed to the dust on the surface of the cover glass and then to the object itself, but the result so obtained will be too small, and must have one-half as

much added to it. If the motion of the adjustment is ten divisions, the true thickness is 15.

Cleansing cover glasses.

It is essential that cover glasses before use should be thoroughly cleansed, and all specks, hairs, and fibres be removed. In most cases a little soapy water will remove all dirt and grease, after which they should be rinsed in clean water and dried with a clean linen duster or chamois leather. Some microscopists use two flat boards covered with chamois leather, between which the cover glasses are rubbed, reversing the glass during the process to make sure that it does not adhere to one board, thus cleaning only one side.

Thickness of cover glass.

With low-power object glasses—1½ inch (32 mm.), 2/3 inch (16 mm.), 1/3 inch (8 mm.)—the thickness of cover glass used is of little importance; but for high powers—1/6 inch (4 mm.) or higher power dry lenses—it is most important to always use the thinnest covers (No. 1), because with high-power object glasses which are not immersion lenses a variation in the thickness of the cover glass affects the correction of the object glass. An object glass can only give the most perfect image when used with a cover glass of a particular thickness, and they are always adjusted for the No. 1 cover glass (see page 81). The 1/6-inch (4-mm.) object glass is very sensitive in this respect, and one apochromatic lens of this power is provided with a correction collar to adjust for cover glass of different thicknesses. As microscopic cover glass is sold by weight, the cost of the No. 1 glass is not materially more than the No. 2 or 3, because a larger number go to the ounce.

If a specimen in the nature of a leaf, a fibre, or powder, is to be examined under a high power, it is best to place such a specimen on a glass slip and place a cover glass over it to flatten it out and hold it in position, preferably in a drop of water.

Glass slip with ledge.

In this case a slip with a ledge against which the cover glass may rest is a convenience.

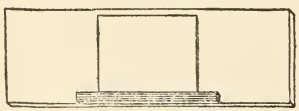


Fig. 48.—No. 3406, Slip with Ledge.

If the specimen is to be examined in fluid, a drop should be placed on the slip and a cover glass put down over it at an angle in such a manner that the cover glass touches one side of the drop first, and is then allowed to gradually fall so as to prevent air bubbles being enclosed (Fig. 49).

Fig. 49.

Blood films.

Blood films, or specimens of bacteria which are to be examined and then destroyed, may be dried by heating over a spirit lamp upon the slip or cover glass. If they are to be examined

with a dry object glass, they should be dried upon the cover glass and placed film downwards upon the slip. If an immersion object glass is used they may be dried on to the slip and the use of a cover glass dispensed with, for the whole space between the object and the lens is filled with what corresponds to glass. The thickness of the cover glass, therefore, makes no difference optically, but unless the object is thoroughly dried a cover glass may be required to prevent the object from floating off into the immersion fluid. By putting a drop of Canada balsam between the cover glass and the slip, and firmly pressing them together, a permanent mount may be prepared.

Examination of objects in fluid.

When objects in a drop of fresh or salt water are placed between a cover glass and a slip, the superfluous fluid around the cover glass should be removed with blotting or filter paper, and capillary attraction will hold the cover glass in position when the slide is placed at an angle.

If a specimen is to be examined for a long period, a piece of cotton may be placed between the cover glass and the slip, one end of which dips into a bottle or capsule of water at a higher level than the slip, and the other in a similar bottle at a lower level. By this means the slide will be kept moist and objects can be kept alive for a considerable period.

Slip with hollow.

Small organisms, such as infusoria, bacteria, or protozoa, have sufficient room in the thin layer of water between the cover glass and the slip to live and move freely, but larger objects, such as rotifers, entomostraca, etc., require more room. For use with such objects, slips are made with cavities, and are known as slips with hollows. They are used in the same way as ordinary slips, the water which fills the cavity holding the cover glass in position by capillary attraction.

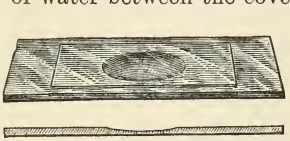


Fig. 50.—No. 3405.

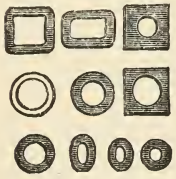


Fig. 51.—Cells.

Cells.

Cells or rings of vulcanite metal or glass may be cemented to 3 × 1-inch slips with Hollis glue, forming deeper cavities for the reception of large specimens (see page 58). When such objects are in fluid, the removal of the superfluous water is sufficient to make the cover glass adhere to the cell. If insects are to be examined dry, the cover glass may be made to adhere to the cells by placing a smear of grease or vaseline around the upper edge.

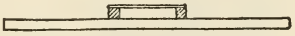


Fig. 52.—Slip with Cell and Cover.

Trough.

For the examination of aquatic weeds, algæ, and animalcula with low powers, a trough is a useful apparatus. Fig. 53 shows a

convenient form mounted on a 3 × 1 slip; it has usually a space for water about 2 mm. thick. It is made with an upper glass either of thin microscope cover glass, about ·25 mm. thick, or a thicker glass about 1 mm. thick.

Fig. 53.—No. 3413, Slip with Trough.

Fig. 54 shows a glass trough cemented together. This has dimensions of $1\frac{1}{2} \times 1\frac{1}{4} \times \frac{1}{4}$ inches, and is made of glass about 1 mm. thick. It is only suitable, owing to the thickness of the glass, for use with low powers.

Adjustable trough.

A very useful form of trough, known as Beck's glass trough, is made of a 3 × 1 glass plate, into which are fixed two screws and milled nuts, each holding a clamping plate. A half-circle of indiarubber made from an elastic band is laid on the 3 × 1 slip, and a glass cover plate of any required thickness is placed on the top. The whole is clamped together by the milled nuts. As all the parts take to pieces, it can be readily cleaned, and cover glasses or separating bands of any thickness can be used. Separating bands of the very thinnest material, such as dental rubber, or even paper, can be used, so that the layer of material being examined is exceedingly thin. This is of great convenience when it is desirable to examine the specimens by dark-ground illumination or with high powers. It is a very convenient appliance also for the examination of aquatic specimens. These can be first arranged in position on the lower 3 × 1-inch slip within the area surrounded by the rubber band, the cover may then be placed in position and sufficient fluid dropped in. If a small circular cover glass be cemented in the centre of the 3 × 1-inch lower glass, a small drop of fluid can be confined to the centre of the field for examination. It can be used with substage condensers or dark-ground illuminators.

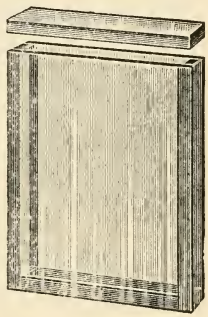


Fig. 54.—No. 3415, Trough.

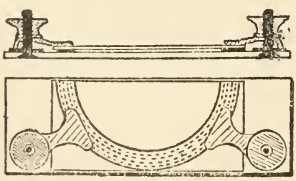


Fig. 55.—No. 3416, Beck's Glass Trough.

Live box.

A live box consists of a plate 3 × 1 inches, with an aperture in the centre of which is fixed a short brass tube carrying at the top a glass plate. Over this tube slides a cap, in the top of which a cover glass is held by a screwed cell. The object to be examined

is held between the two glasses. This appliance is useful for examining living insects or for flattening out thin, uneven objects, such as a piece of a leaf or fabric. It is chiefly used with low powers, as substage illuminating apparatus cannot be readily used.

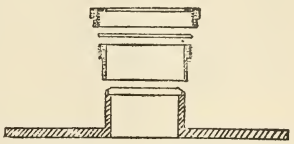


Fig. 56.—No. 3420, Live Box.

A form of live box known as the Rousselet live box is useful for high powers. The principle is that of an ordinary live box, but the fixed lower glass plate is on the level of the stage, and a substage condenser or high-power illuminator can be used with this live box. When a very small object is to be examined, a still smaller cover glass may be cemented with Canada balsam to the centre of the lower glass plate, and the object is thus confined to the centre of the field. It is $2\frac{3}{4} \times 1\frac{3}{4}$ inches, and is not suitable for use on a mechanical stage.

Compressor.

The Beck compressor is a 3 × 1-inch plate of glass at one end of which a circular pillar is fixed. This pillar carries an arm which holds a thin cover glass $3/4 \times 1\frac{5}{8}$ inches. The arm is raised or lowered by a screw at the top of the pillar, which mechanically varies the space for holding the specimen. The arm carrying the thin glass can be swung to one side for placing the specimen in position and then lowered to the required amount.

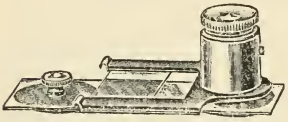


Fig. 57.—No. 3421, Beck's Compressor.

For many purposes this compressor is more convenient than a live box, for by means of the delicate screw motion a living object may be held stationary without being crushed. Also, the slip being made of glass, it can be kept clean, and the thin glass which is attached to the arm by spring clips can be readily removed for cleaning, or replaced if broken. It can be used with substage condensers and dark-ground illuminators.

Stage forceps.

A convenient method of holding small solid objects for observation under the microscope is by means of a pair of stage forceps, which are attached to a 3 × 1-inch ebonite plate. The plate is either held by the mechanical stage or, if the microscope is not fitted with the latter, by means of the spring stage clips. On the plate is a metal fitting holding a rod, which has at one end a small pair of spring forceps opened by pressing the two pins together, while at the other end is a cork into which specimens may be pinned. The forceps can be unscrewed from the rod,

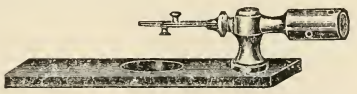


Fig. 58.—No. 3422, Stage Forceps.

which can then be reversed in its fitting so that either the forceps or the cork can be brought into the centre of the field; they can also be rotated so that all parts of the object they hold can be examined. This apparatus is useful for the examination of small insects, botanical specimens, fragments of rock, tissues, and other small solid bodies.

A case can be supplied containing apparatus for holding objects, which includes 3 × 1-inch slips, a slip with ledge, a slip with hollow, a trough on slip, a Beck glass trough, a live box, a Beck compressor, stage forceps, and a supply of thin glass. The Rousselet live box is not included, as it is not of the standard 3 × 1-inch size.

Mounting specimens.

Mounting permanent specimens for the microscope is a subject that is beyond the scope of this book. The microscopist should be provided with a bottle of Canada balsam dissolved in benzol or xylol, which is a transparent cement, and a bottle of Hollis glue, which is a brown shellac cement. Many objects can be mounted by means of these two cements. Small shells, botanical and entomological specimens, diatoms, and other small objects may be attached to a 3 × 1-inch slip with gum or Canada balsam inside a cell of paper, vulcanite, or glass of a thickness sufficient to protect them, and with a cover glass cemented to the cell. A narrow ring of cement of the diameter of the cover glass, dried upon the slip, is often sufficiently thick to protect small objects when a cover glass is cemented to the surface of this ring.

Turntable.

A turntable (Fig. 59) is an appliance for making rings of cement on a 3 × 1-inch glass slip and for placing a protecting ring of cement round a circular cover glass or cell after it has been cemented on. The slip is held on to the circular revolving table by spring clips, and by holding a camel's-hair brush, which has been dipped into cement, against the slip as this table spins round, a layer of cement is left in a neat circular ring.

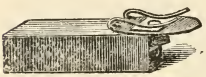


Fig. 59.—No. 3386, Turntable.

Many objects can be placed on a slip and a drop of Canada balsam dropped upon them, a cover glass being then placed over the drop before it has set. The specimen is thus permanently preserved. This is all that is required with such specimens as dried blood films or stained bacteria.

It is essential, however, that such specimens should not be moist, as water will not mix with Canada balsam, and some objects require to be first soaked in absolute alcohol or turpentine to remove the water or air.

Hæmacytometer.

The hæmacytometer is an apparatus for counting the blood corpuscles, and consists of a counting chamber, two mixing pipettes, and suitable optically plane cover glasses. The blood is first diluted with a solution known as "Toisson's" solution, for either

the red or white, or with a solution of acetic acid when a count of white cells only is being made. In counting red corpuscles a dilution of 1–200 is generally used, but in certain cases 1–100 may be employed. The blood is drawn into the pipette up to the mark 0·5 in the case of 1–200 dilutions, and up to the mark 1 for 1–100 dilutions. The pipette is then immediately placed in the

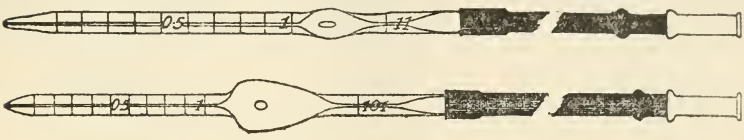


Fig. 60.—No. 3325A, Pipettes for Red and White Corpuscles.

diluting fluid, which is drawn up to the mark 101 above the bulb. Both ends of the pipette are then closed with the fingers, and the pipette shaken to ensure an even mixing, the glass bead in the bulb facilitating this. For white corpuscles, a dilution of 1–10 is employed and the other pipette is used. For filling the counting chamber, a drop of the mixture is blown out of the pipette, after allowing several drops to go waste, into the centre of the counting chamber. The cover glass is then placed over the cell. The drop of blood must not be allowed to overflow the platform into the groove which surrounds it, and the cover glass must be in perfect contact with the object slide, and all must be scrupulously clean.

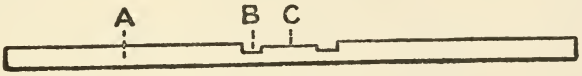


Fig. 61.

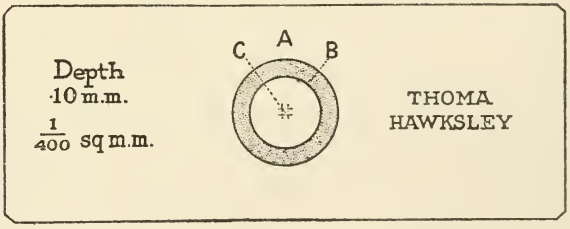
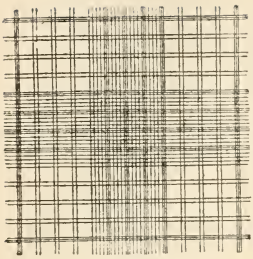


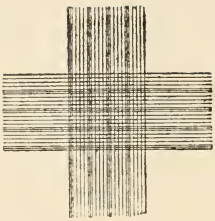
Fig. 62.—No. 3325A, Thoma-Hawksley Counting Chamber.

The counting chamber consists of a plate of glass with an annular groove ground upon it. The circular portion inside the groove is ground and polished to a distance of ·1 mm. below the level of the plate of glass.

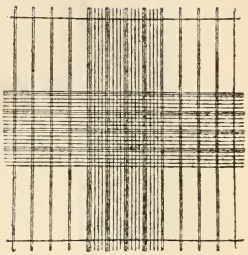
In the Thoma hæmacytometer this portion is ruled with a diamond into squares 1/400th of a square mm. each in area. It



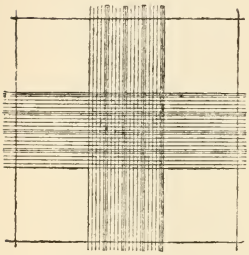
Türck.



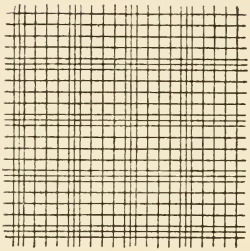
Thoma.



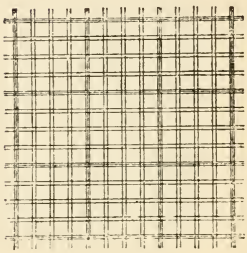
Elzholz.



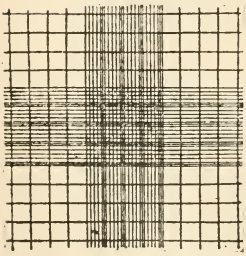
Zappert.



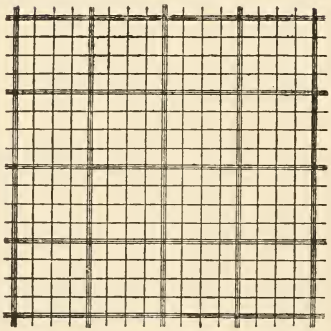
Centre Ruling of Thoma.



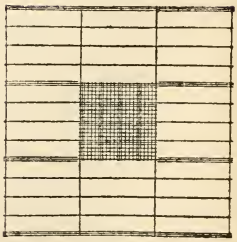
Bürker.



Nebauer.



Füchs and Rosenthal.



Breuer.

Fig. 63.—Rulings.

will therefore be seen that the amount of liquid resting upon each square has a cubic capacity of 1/4,000th of a cubic mm. The liquid which has been placed in the counting chamber is allowed to settle, and the corpuscles will therefore be in contact with the bottom of the cell. It will be found that it is a simple matter to count the corpuscles contained in each square. The usual method is to count, say, 100 squares, and it must be noted that in dealing with those actually on the lines, only those on two sides of the square should be counted, and this rule should be applied throughout.

The number of corpuscles in 1 cubic mm. of undiluted blood is then obtained by multiplying together the rate of dilution, the number of corpuscles counted, the volume of each square (1/4,000th of a cubic mm.), and dividing by the number of squares counted. The above is the general method of counting the red corpuscles; but in the case of the white corpuscles, as there are a very much smaller number of these, the method generally employed is to count the total number of the whole ruled area of the counting chamber, which is 1 sq. mm.

There are other forms of counting chambers, such as the Bürker, Füchs-Rosenthal, Breuer, and Zapperts; the method of employment in all these is the same, but the ruling and also the counting are different in each case.

The use of a mechanical stage greatly assists the counting.

A simpler form of hæmacytometer can be used which depends for its action on Mr. Rheinberg's beautiful process of making graticules and glass scales. A glass plate is photographed with squares in the pattern of a chess-board, so that alternate squares are tinted, although they are transparent. This plate is dropped into an eyepiece between the lenses, and by means of a stage micrometer the drawtube can be varied until a definite number of squares are equal to ·1 of a millimetre in the micrometer. The chess-board glass plates are supplied with squares either 1/4, 1/2, 1, or 2 mm. in size. They are made to cover the whole field of view, or as a small block of squares in the centre of the field. The latter are to be preferred for blood counts.

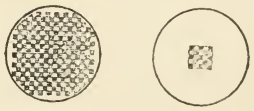


Fig. 64.

The only other requirement is a 3 × 1-inch slip with a metal ring cemented to it which is ·1 mm. thick, into which the blood is placed covered with an ordinary cover glass. Suppose a 1/6-inch object glass is being used, a 1-mm. chess-board plate dropped into the eyepiece can be made by drawing out the drawtube to the required position according to the eyepiece and object glass employed, of such an apparent size that nine squares, three each way, correspond to ·1 mm., and the count of nine squares will give the number in a cubic tenth of a millimetre. If a 1/2-mm.

chess-board plate be used, then thirty-six squares, six each way, correspond to a cubic millimetre. The most convenient size to select will depend upon the class of object to be counted and the object glass that is used.

Due to the alternate squares being tinted, a count can be made with much less eye-strain than with the ordinary hæmacytometer, and this method is preferred by some apart from the question of the cost of the apparatus.

Culture plates.

The preparation of culture plates and the methods of cultivation will be found in text-books on bacteriology. They are large square plates covered on one surface with nutrient gelatine, upon which isolated colonies of bacteria are growing. They should be examined with a low-power 1½-inch (32-mm.) object glass, the mechanical stage having been removed from the surface of the stage for the purpose. The required colonies having been recognised, a morsel of the gelatine can be removed with a platinum needle, while the colony is in the field of the microscope, and can be smeared on a cover glass. A drop of distilled water having been added, it can be spread out on the cover glass and examined in a living state with the high-power dark-ground illuminator or dried in a spirit flame, stained and mounted on a 3 × 1-inch slip with a drop of Canada balsam.

Warm stage.

A warm stage is an apparatus for applying warmth to a specimen under continuous observation. A simple form consists of an oblong copper plate 3 × 1 inches, from one side of which projects a long narrow strip and which has an aperture 1/2 inch diameter in the centre of the 3 × 1-inch portion. It is placed on the stage of the microscope and held like an ordinary 3 × 1 glass slip in such a position that the long strip projects in front of the microscope. A spirit lamp is placed under the far end of the projecting strip and adjusted so that its flame impinges on the strip, or is slightly to one side, until the portion of the copper plate which is near the 1/2-inch aperture is at blood heat. The correct temperature is readily ascertained if a small piece of a mixture of cacao butter and wax is placed on the copper near the aperture. The mixture is made in such proportions that it melts at blood heat, and when the piece melts on the copper the correct temperature has been reached.

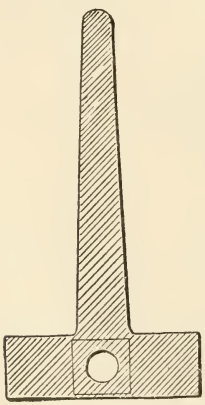


Fig. 65.—No. 3384, Warm Stage.

The drop of fluid to be examined is placed on a large cover glass and a smaller cover glass is placed over it, and the two laid upon the copper plate. To prevent evaporation the upper

cover glass should be smeared round its edge with olive oil or vaseline.

Centrifuge. A centrifuge is a small hand machine for revolving test tubes of fluid at a very rapid speed, so that the heavy portions of sediment may be rapidly separated from the fluid. Two glass test tubes encased in aluminium covers are revolved at a speed of about 2,500 revolutions per minute by turning a handle. The examination of urine is greatly facilitated by this method, and hyaline cysts can be deposited without breaking them or altering their form. Milk is separated by the centrifuge so as to give the percentage of fat, and micro-organisms can be readily concentrated to the bottom of the test tube, from which they may be extracted with a pipette.

Micro-spectroscope. A simple microspectroscope for the examination of blood has been designed by Mr. Rheinberg; it consists of the micrometer eyepiece, as described on page 68, with a slit in the position where the divided glass plate is generally placed, and a diffraction grating placed in the eyepiece. On looking through the eyepiece, the slit is observed, while to one side a spectrum is formed. If a low-power object glass be used, and the object to be examined placed on the stage of the microscope, its spectrum will be seen some little distance to one side of the slit. If a comparison slide of a fluid be prepared close to the edge of a glass slip, it can be placed on the stage in contact with the fluid to be examined on the edge of another slip, and the two spectra can be seen at the same time one above the other. If colour filters are to be examined they can also be compared by this method. It is very useful for the examination of blood, chlorophyll, dyes, or other colouring matter.

Metallurgical specimens. The preparation of metallurgical specimens for examination under the microscope consists of cutting off a small piece of the metal to be examined with a hacksaw and grinding a small portion to a flat surface and polishing it. It is then etched with such solution as will remove certain constituents from the surface, leaving the rest unaffected. Where a fracture of steel is to be examined, it is sometimes advantageous to cover it, before grinding and polishing, with a coating of copper by electroplating, as by this means a fractured edge shows up very clearly against the different colour of the copper.

Mounting specimens with wax. The piece so polished is then mounted by embedding it in a lump of wax placed on the slide. The best wax for this purpose is one prepared in such a manner that it will hold its position for a long period and yet remain plastic under pressure. It is known as S.I.R.A. wax. The specimen should be attached so that its surface is parallel to the slip upon which it is mounted, and this is done most readily as follows:

Cut two square or circular pieces of wood or vulcanite from the same piece of material of a thickness greater than the specimen

and about 1 inch diameter. Lay one of these at each end of a 3×1 glass slip, and lay the metal specimen face downwards on the glass slip in the space between the two pieces of wood. Take another 3×1 slip with a lump of wax adhering to the centre, and, holding it with the wax downwards, press it down upon the wooden plates until it is in contact with them; the wax will adhere to the metal specimen and cement it to the upper slip. This can now be removed and turned over, and the specimen is ready for examination (see Fig. 66).

Fig. 66.

Grinding and polishing specimens.

The grinding and polishing is generally done on a machine with a horizontal revolving disc with carborundum and emery, and polished on the same machine with rouge or diamantine. The following describes a special machine made for the purpose which is driven with an electrometer from the ordinary lighting circuit.

Grinding and polishing machine.

It is complete and self-contained, and only requires to be connected with the electric current supply by the usual fittings to be ready for immediate use.

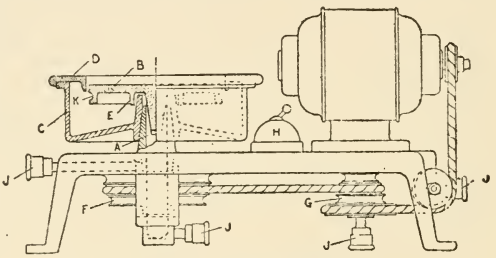


Fig. 67.—No. 1290.

Fig. 67 gives a general view of the machine, which consists of a vertical spindle carrying a grinding or polishing disc, driven by a small electric motor.

The machine consists of a vertical spindle (A) carrying a grinding or polishing disc (B) driven by a small electric motor (L), and gives in a compact, convenient form all that is required for preparing metal specimens for examination.

Fig. 68.—No. 1292.

The spindle (A) is made of steel, and is bored out at the upper end to receive the disc upon which the polishing or grinding material is to be placed. The lower end is hardened to prevent undue wear. This spindle is furnished with a speed cone (F), with pulleys of varying diameters, and is driven by means of a belt from the driving

cone (G), which in its turn is driven from the motor. By shifting the belt on the speed cone, a range of speeds varying from about 300 to 1,000 revolutions per minute can be obtained.

The disc B is made of brass, and fits, by means of a tapered fitting, into the spindle A, which allows of its easy removal and at the same time ensures accuracy in the running.

A lip (E) projects downwards and prevents any grinding or polishing material reaching the bearing.

The cloth for polishing, or emery paper for grinding, is secured to the disc by a simple but very effective device. A groove (K) is made in the edge of the disc, and the paper or cloth is stretched over the surface of the disc and is held in position by means of a garter made of a stiff brass spiral spring, which presses the material into the groove. In this way the cloth, or paper, is held in contact with the disc, no matter what its thickness may be (see Fig. 68).

In order to collect the spent polishing materials, the disc is surrounded by a catcher (C), which can be easily removed for cleaning. In the top of the catcher is fitted a guard ring (D) which, being wide, forms a rest for the hand, and by being continued downwards below the surface of the disc, and nearly touching the edge, prevents any specimens that are being polished from falling into the catcher should they be let slip from the fingers.

Fig. 69. — Pipettes.

This ring is also used for stretching the paper or other material on the disc in the following manner:

The catcher (C) being removed, the paper or material is placed on the disc (B) and the ring (D) pressed over the paper until the ring (D) is about half-way down the edge of the disc (B). The spring garter is stretched over the edge. The ring (D) is now pressed right down over the disc, and the garter spring is pressed home into the groove.

If it is desired to remove a piece of paper that has been fitted to the disc so as not to disturb the folds of the paper, the garter spring should be removed downwards. The paper should be replaced in the manner described above.

Should the disc at any time become so firmly fixed in the spindle that it cannot be removed by hand, a pair of lifting levers are supplied, which can be placed resting on the edge of the catcher with one end under the disc; a steady pressure on the other end will raise the disc from its fitting in the spindle.

A cover is provided to protect the revolving disc from dust when it is not in use.

The motor is supplied with flexible connecting wire and plug adapter, so that it can be connected with any ordinary lamp fitting.

The machine can be made to suit any voltage specified, and for direct or alternating current; in the latter case, the phase, cycle, etc., must be given.

Pipettes.

Pipettes (Fig. 69) are small glass tubes of various shapes, and are useful for taking specimens out of fluid and transferring to the slip or object-holder for examination. If the upper end of the tube be closed with the finger, the lower end can be immersed in a fluid, and the air within the tube prevents the entrance of the liquid. On removal of the finger from the upper end, the fluid enters the glass tube, carrying with it small bodies suspended in it; by replacing the finger, the fluid will be retained in the tube, and thus transferred to a slip, live box, or compressor. Two or three needles, a pair of fine forceps, a pair of scissors, and a scalpel are required for the manipulation of unmounted objects before examination. For the collection of aquatic organisms from either fresh or salt water, a collecting stick and net are of great use. The net is made of fine bolting cloth, and is of a conical shape with a glass bottle secured to its apex (Fig. 71). A surface net that is towed behind a boat may be made in a similar manner, and should be provided with a small calico bag attached to its front edge which may be filled with stones to enable it to be towed along when sunk below the surface of the water.

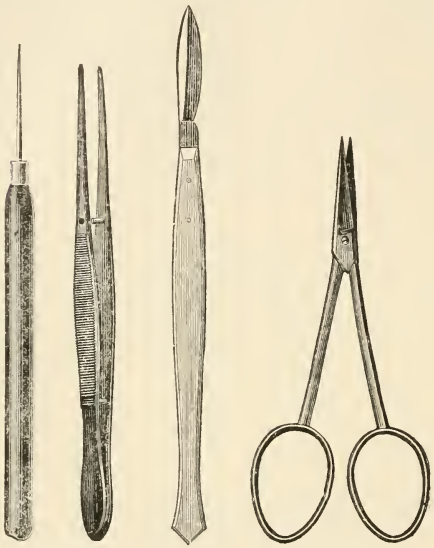


Fig. 70.—Dissecting Instruments.

Instruments.

Fig. 71.—No. 3460, Collecting Net.

Collecting net.

Most of the free swimming fauna in open water are near the surface during the day, but there is often a great variation in the fauna to be found at different levels.

CHAPTER IV

SUNDRY APPARATUS

Drawing microscope specimens.

THE drawing of specimens seen under the microscope by free-hand suffers from the disadvantage that it is difficult to obtain accuracy in dimensions and relative proportions. Microscope drawings are seldom required as works of art, but must be accurate. The simplest aid to accurate drawing is paper ruled with lines in squares used in combination with a glass plate ruled into squares dropped into the eyepiece of the microscope. If the top lens of the eyepiece be unscrewed, it will be seen that about half-way down the tube there is a stop; a ruled plate (Fig. 72) can be dropped upon this stop, when it will be found to be in the focus of the top lens. If the lines are not quite distinct when the top lens is screwed home, the latter may be slightly unscrewed till the lines come sharply into focus.

Ruled squares.

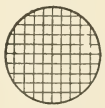


FIG. 72. — No. 3279, Ruled Eyepiece Plate.

This method of drawing is popular because the position of the main outlines and salient features of an object can be accurately ascertained, and as much of the detail as is desired filled in freehand. A sketch showing the points of importance, leaving out much of the extraneous detail, is sometimes of more scientific value than a photograph, which shows so much detail that it is difficult to pick out the features of special interest.

Measuring specimens.

Objects sketched in this manner may be measured by reference to a stage micrometer. This is a 3 × 1-inch glass slip with lines ruled on it 1/10 and 1/100 of a millimetre, or 1/100 and 1/1000 of an inch; and if it be placed on the stage of the microscope and viewed under the same conditions as the object that has been drawn by means of the squared paper, it is easy to see how many 1/100ths of a millimetre or 1/1000ths of an inch are included in each square. This can be noted on the paper, and the dimensions of the object may be obtained by measuring the drawing.

A glass plate 4 × 1 inches, with divisions etched on its lower surface, is the most convenient scale for making such measurements on the drawing.

The measurement can also be made without making a drawing, for once the value of a square in hundredths of a millimetre or

thousandths of an inch has been ascertained with a particular object glass and a particular tube length, the measurement can be made direct in the microscope. For this purpose ruled squares in the eyepiece are not always convenient. An eyepiece micrometer is a plate of glass ruled with a finer series of lines (Fig. 73). It drops into the eyepiece in a similar manner to the square ruling. An even better method of making such measurements is by means of the Beck micrometer eyepiece.

Ruled micrometer.

Fig. 73.—No. 3276, Eyepiece Micrometer.

Micrometer eyepiece.

This consists of a complete eyepiece with a magnifying power × 8, and a special vernier millimetre scale (A, Fig. 75) placed in its focus which is outside the lenses.

It is provided with a collar (B) which fits over the draw-tube and can be clamped in position by a milled head (C). The eyepiece itself can be focussed up and down by revolving it in its fitting till the scale A is in exact focus for the observer's eye.

The scale (Fig. 76) is in millimetres with a vernier reading to 1/10th of a mm.

On the left is a vertical series of divisions divided in half-millimetres for rough measurement. For fine measurement the object to be measured is placed in a horizontal position, and the length is measured in 1/10th mm. by use of the slanting line on the right. The image of an object as shown in the diagram measures 3·25 mm., because it covers three large divisions and extends to the oblique line at a point half-way between the ·2 and ·3 of tenth-millimetre vernier divisions.

To obtain the actual size of the object itself, this result has

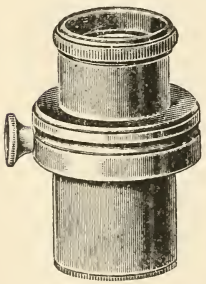


Fig. 74.—No. 3275, Micrometer Eyepiece.

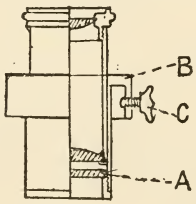


Fig. 75.—No. 3275, Micrometer Eyepiece.

Fig. 76.—Scale of Micrometer Eyepiece.

merely to be divided by the initial magnifying power of the object glass. (See table of magnifying power on page 77.)

In cases where great accuracy is required, each object glass can be verified as to its initial magnifying power by the use of a

stage micrometer. For this purpose, focus the scale of a stage micrometer carefully; if 1/10th of a millimetre now measures 2·5 mm. in the scale with the correct tube length of 160 mm. and a particular object glass, the magnifying power of that object glass is 25.

Initial magnifying power.

The first image formed by a microscope is produced by the object glass at a position rather above the stop of the eyepiece. This initial magnification depends on the focal length of the object glass, and also the position of this image, which is governed by the length of tube of the microscope. The approximate initial magnifying power of each object glass or the enlargement produced in the first image is engraved on each Beck object glass for a standard tube length of 160 mm. It can only be approximate, because different eyepieces have their stops in slightly different positions, and therefore a small variation in the theoretical tube lengths is caused by the use of different eyepieces. The eyepiece magnifies the first image formed by the object glass by a fixed amount, according to the focal length of the eyepiece, and does not vary, and the total magnifying power at the 160-mm. tube length is obtained by multiplying the power of the object glass by the power of the eyepiece.

The Beck micrometer eyepiece measures the size of the first image formed by the object glass in millimetres and tenths of a millimetre. The result obtained when the drawtube has been set at 160 mm. has only to be divided by the initial magnifying power of the object glass to give the actual size of the object being measured.

Small variations may occur in individual lenses, but they are usually not sufficiently great to be of consequence in ordinary work.

Horizontal camera lucida.

The camera lucida is an apparatus for making correct drawings. It is made in four models, suitable for three different positions of the microscope.

The Beck horizontal camera lucida (Fig. 77) requires the tube of the microscope to be in a horizontal position, and the paper upon which the drawing is to be made placed upon the table below the eyepiece of the microscope. The camera lucida is a small half-silvered prism held in a mount which fits on to the drawtube of the microscope in such a position that one surface is close to the front lens of the eyepiece. The observer places his eye immediately above the prism, and the image seen in the microscope is reflected

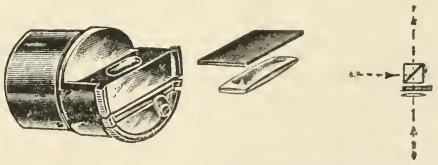


Fig. 77.—No. 3368, Horizontal Camera Lucida.

upwards into his eye by means of a reflection in the prism from a half-silvered surface. The eye also sees the paper and pencil through the half-silvered surface, and can draw the object seen through the microscope accurately and rapidly, because it appears to be superimposed on the paper.

If the eyepiece of the microscope is closer to the paper than about 10 inches (the near point of vision), the pencil will not appear sharp ; and to obviate the necessity of raising the microscope, a lens is supplied below the prism which enables the pencil and paper to be clearly seen at a distance of about 6 inches, which is the usual height of a microscope body. The lens is also a great assistance even when the paper is 10 inches away. It fits into a recess in the mount and is held in by a turn-button.

The Beck horizontal camera lucida is superior to the old Wollaston form, as the eye does not require to be held in an exact position during the process, and there is no training required for its use. The only care that is required is to see that neither the illumination of the object nor the paper is so brilliant as to obscure the one or the other. The relative illumination can be easily regulated by a neutral tint glass placed either between the prism and the paper to reduce the apparent brightness of the paper, or between the microscope eyepiece and the prism to reduce the apparent brightness of the microscope image, or the illumination of the microscope may be varied by any of the means previously referred to. A slot is provided in the two positions to receive the neutral glass.

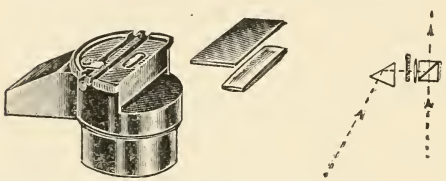


FIG. 78.—No. 3369, Beck Vertical Camera Lucida.

Vertical camera lucida.

The Beck vertical camera lucida (Fig. 78) is a prism which acts in a similar manner except that the microscope must be placed in a vertical or an inclined position. When the microscope is in a vertical position, the drawing paper must be placed on a slanting board at an angle of 30° in front of the microscope. In other respects the manipulation is the same. When the instrument is used in an inclined position, the tube of the microscope must be set at an angle of 60° and the paper may be placed upon the table. The same arrangements are made for the reception of the lens and neutral glass.

Abbe camera lucida.

The Abbe camera lucida (Fig. 79) consists of a prism over the eyepiece and a large mirror placed a few inches to one side in a horizontal direction. The prism has a completely silvered surface, with a small aperture in the centre, and is not so easily

used as any of the other forms. With this apparatus the instrument is placed in a vertical position, and the drawing paper

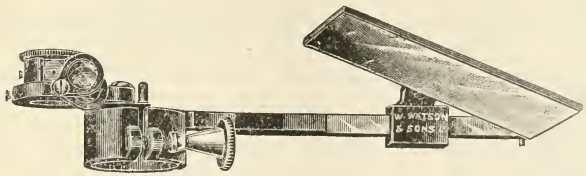


Fig. 79.—No. 3370, Abbe Camera Lucida.

placed on the table at one side. The mirror must be inclined at such an angle that the centre of the field of view appears below the centre of the mirror, or a distortion in the picture will be caused. This generally limits the size of the drawing to a small portion of the centre of the field of view, because of the closeness of the mirror to the side of the microscope. This can be remedied if the paper on which the drawing is to be made be tilted up so that the distortion is corrected, for the image can then be thrown to a greater distance to the side of the instrument. In order to find the correct angle at which the paper should be tilted to avoid distortion, the circular margin of the field of view as seen upon the paper may be measured in two directions, sideways and fore and aft, and the angle of the paper altered till the two measurements are the same. This method can also be adopted with the Beck vertical camera lucida, when it is required to set the inclination of the microscope or drawing-board to the correct angle experimentally.

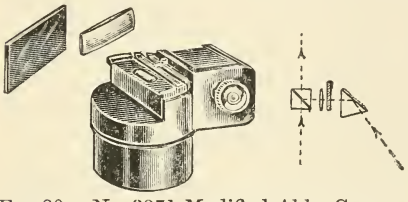
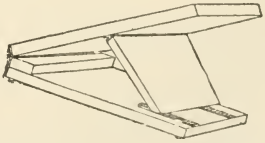


Fig. 80.—No. 3371, Modified Abbe Camera Lucida.

A camera lucida (Fig. 80) of the Abbe type is made in which the bulky mirror is replaced by a small tilting prism attached close to the eyepiece, and the prism is half-silvered. In this case the drawing-board must always be placed at an angle which can be ascertained as explained above. A lens and neutral tint glass can be used in the same manner as previously described.



Modified Abbe camera lucida.

Fig. 81.—No. 3375, Drawing Table.

Drawing table.

A table (Fig. 81) which can be set at any desired angle is supplied which is a convenience where the drawing paper requires

to be at an inclination. It is marked for the correct position for the use of the Beck vertical camera, or may be set at any other position.

Finders.

A large amount of time is saved in examining specimens if the position of a particular object or of a portion of a slide can be recorded for future reference. For this reason mechanical stages are provided with divided scales and verniers. The readings of these scales are taken when the desired object is in the centre of the field. These readings can be written on the label on the slide, and the object in question can always be found again by setting the stage so that the scales read these numbers.

Vernier.

For those who are not familiar with the use of a vernier, the following description may be useful. The scales of the mechanical stages are all divided in millimetres with a vernier which reads to 1/10 of a mm. For a rough reading the first line with arrowhead on the right-hand scale (Fig. 82) may be used as an index, and the distance which it is beyond one of the lines estimated, thus the reading of the scale as shown in the figure would be about 13½. For a more accurate reading the other lines on the right-hand scale, which form what is known as the vernier, should be examined. The line with arrowhead is not opposite any division on the long scale, but it will be found that one of the lines on this scale is opposite a division—in the case illustrated it is the fourth line—this shows that the true reading is not 13½, but is 13·4. If it had been the eighth line that was opposite a division, it would have been 13·8, and so on.

Fig. 82.—Vernier.

Polarising apparatus.

Polarising apparatus consists of a polarising (Nicol) prism in a revolving fitting which pushes into the substage of the microscope, a plate of selenite in a detachable tube sliding over the polarising prism, and an analysing (Nicol) prism in a revolving mount which screws into the nosepiece of the microscope between the body of the microscope and the object glass. An analysing prism in a special eyepiece may be used instead of the analyser over the object glass if preferred. A polarising apparatus is essential for the study of rocks, and is always supplied in petrological microscopes; but it is used on an ordinary microscope for the study of crystals, starch, and many organic substances. A starch granule can always be recognised by its means, as it shows under polarised light a black or coloured cross, due to the crystalline refraction of the material. Sugar and other crystals display brilliant colours, and such materials as horses' hoofs, wax, or finger-nails, show the structure in a manner that is not otherwise seen. An explanation of the reason for the appearances obtained with polarised light involve a full discussion

of the theory of light, which is not within the scope of this book.

An eyepiece with a movable pointer or indicator (Fig. 83) is a useful aid to teaching. It consists of an eyepiece magnifying $\times$ 10, which has a fine movable index which can be made to point to any portion of an object under consideration, or can be turned out of the field when not required. It is invaluable for demonstrating cell-structure, crystals, etc. Demonstration eyepiece.

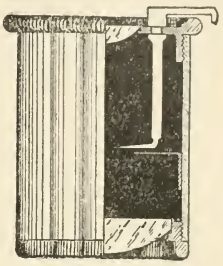


Fig. 83.—No. 3263, Eyepiece with Indicator.

An eyepiece with a pair of cross lines (Fig. 84) is necessary for petrology where angles are to be measured by means of a rotating stage, and is useful for other purposes. Eyepiece with cross lines.

An eyeshade (Fig. 85) which clips on to the drawtube of the microscope obscures the unemployed eye and saves much inconvenience and eye-strain with a monocular microscope. It enables the observer to keep both eyes open without his attention being diverted. Eyeshade.

An erecting eyepiece is a very low-power eyepiece which does not invert the image. It drops into the tube of the microscope in the ordinary way, and is made for use with a 2/3-inch object glass. It gives a magnifying power from 10 to 40 diameters by extending the drawtube. It gives a very large field of view and an erect image, so that it at once converts an ordinary microscope into a thoroughly efficient dissecting microscope; and a slight alteration in the length of tube gives great variation in magnifying power. Erecting eyepiece.

Fig. 84.—No. 3264, Cross Lines of Eyepiece.

To take photographs through the microscope which are entirely satisfactory for most purposes is simple, and does not require much apparatus or special appliances. Photomicrography

The microscope is first arranged to give the best visual image, the particulars as regards illumination given in the earlier part of the book having been carefully followed. The ordinary eyepiece is replaced by the 30-mm. focus compensating eyepiece, and the photomicrographic camera is attached to the tube of the microscope. The image must now be carefully re-focussed upon the ground glass and the plate-holder inserted. The light is cut off from the microscope by placing a card between the light and

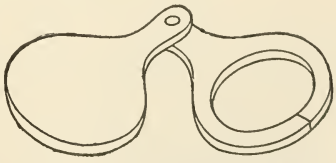


Fig. 85.—No. 3257, Eyeshade.

the stage of the instrument, and the slide of the plate-holder is drawn. The exposure may now be made by withdrawing the card, replacing it and closing the plate-holder.

The use of colour screens (see page 42) is of great service in photography to increase contrasts, but the student is referred to books on this subject for detailed information as to photographing difficult objects.

At the same time, the photography of most microscopic objects is so simple that the ordinary observer need not be deterred by the complexity of the instruction given for the most advanced work.

Vertical photomicrographic camera.

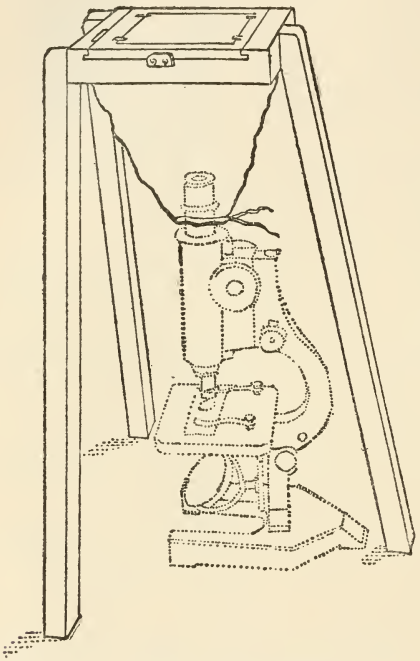


Fig. 86.—No. 3342, Vertical Photomicrographic Camera.

There are two general forms of photomicrographic cameras. One is vertical and is used with the microscope in a vertical position. The other requires the microscope to be placed in a horizontal position, and consists of a metal bar on raising and lowering screws which carries a camera with a variable extension adjusted by means of bellows.

The vertical camera consists of a frame standing on three strong legs splayed out to give stability. It has a slide on its upper surface into which either a ground glass screen or a double plate-holder is inserted. Below this frame is a flexible bag which fits over the upper end of the drawtube of the microscope and can be attached by a cord. The size of plate used is $4\frac{1}{4} \times 3\frac{1}{4}$ inches (quarter-plate), and the distance from the upper end of the standard microscope is such that, with the 30-mm. compensating eyepiece, it gives a circular picture of about 3 inches. It is rigid, and light, and extremely convenient. When the microscope is adjusted with all the care required to obtain the best image the camera is placed over it, attached to the tube by means of the bag, and a touch of the fine adjustment is all that is necessary. In order to focus the image on the ground glass accurately,

a focussing glass should be used; this consists of a high-power lens mounted in an adjustable tube, which can be set so that when it is stood upon the ground glass the latter is sharply focussed. A small portion of the ground glass screen in the centre is left clear so that the image can be viewed with the focussing glass without being partially obscured by the ground glass. Focussing glass.

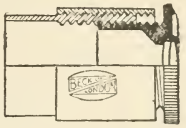


Fig. 87.—Focussing Glass.

The method of setting the focussing glass is as follows: Loosen the top cell which hold s the lens combination by slightly unscrewing it, then screw the outer one of the tubes downwards away from the cell, leaving the screw of the top cell exposed. Now hold the inner tube and screw the top cell backwards and forwards until a pencil mark on the lower side of the ground glass is sharply defined, while the focussing glass is held against the upper side. Then screw up the outer tube, which will form a lock nut and fix the top cell in the correct position.

The horizontal pattern of photomicrographic camera is illustrated in Fig. 88. When this is used, the microscope must be placed with its tube in a horizontal position. It enables a variation in the size of the picture to be obtained according to the extension of the bellows. It is of unusually solid construction. It has an extension of 30 inches and takes a $4\frac{1}{4} \times 3\frac{1}{4}$ inches (quarter-plate) size negative. It consists of a heavy steel hexagonal bar fixed to two steel cross bars which are supported on four levelling screws. Along this bar slide three frames with connecting bellows, each frame being provided with a clamp screw. The frame at one end holds the ground glass or double plate-holder, the frame at the other end carries a flexible bag to attach to the microscope. It can be adjusted up and down so that its centre is at any distance from the ground between $5\frac{3}{4}$ and $7\frac{1}{4}$ inches, and it can be raised to a higher level for use Horizontal photo-micro-graphic camera.

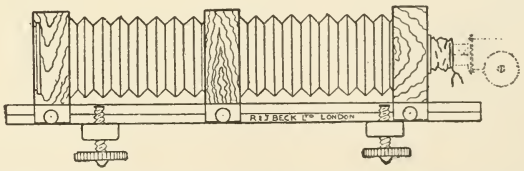


Fig. 88.—No. 3340, Horizontal Photomicrographic Camera.

with large microscopes by putting four feet under the levelling screws.

There are but few purposes for which a larger photomicroscope than $4\frac{1}{4} \times 3\frac{1}{4}$ inches is required, and for this size 30 inches is ample extension.

CHAPTER V

OBJECT GLASSES AND EYEPIECES

The object glasses and eyepieces are of such paramount importance in the performance of a microscope that their use and selection is a matter which should receive the careful consideration of the microscopist. Each object glass is a complicated combination of lenses and metal parts. In some as many as ten, and in none less than four, lenses, mounted in their cells at specified distances apart, form the complete whole. The adjustment and setting of these demands the utmost skill and care in manufacture; an error of 1/10000 of an inch may damage the quality of a high-power lens.

Scratches and dirt on object glasses.

Scratches upon the surfaces of the lens, or dust either on or between the components, unless in an aggravated form, do not interfere with its performance beyond stopping or scattering a little light, but the slightest shifting of one of the lenses or the least smear of grease or moisture will entirely upset the corrections and ruin its performance. No glass surface should ever be touched by the fingers, as they always leave a smear of grease. It is, therefore, of the utmost importance to treat all object glasses, eyepieces, and condensers with care, and to keep them free from moisture, dirt, or grease. They will, even with the greatest care, collect dust from the atmosphere in time, but they should always be kept in a dry place, especially when in a moist climate.

Dirt on eyepieces.

Dirt in the eyepieces shows in the field of view, that on the object glasses is not clearly visible, but may make the image hazy and indistinct. It is quite readily detected in the eyepieces, as by revolving the eyepiece in the drawtube the specks due to dirt in the eyepiece will revolve. If the specks are on the object or in the observer's eye, they will remain stationary.

Cleaning lenses.

To remove dirt from the eyepiece, the surfaces should be carefully cleaned with a very soft piece of well-washed silk; and if after this any still adheres, the silk should be moistened with a little xylol or alcohol. For this purpose it is quite safe for the microscopist to unscrew the cells, which hold the lenses, from the eyepiece tube, provided that care is taken to replace them at the right ends. It is best to only unscrew one at a time. It is inadvisable for the microscopist to attempt to clean the internal lens surfaces of an object glass; the interior surfaces do not readily

List of Standard Achromatic Object Glasses

No.	English Designation.	Focal Length.	Numerical Aperture.	Initial. Magnifying Power.	Magnifying Power with Eyepieces.					Add for each 20 mm. Extension of Drawtube.				
					× 6 42 mm.	× 10 25 mm.	× 15 17 mm.	× 17 15 mm.	× 25 10 mm.	× 6 42 mm.	× 10 25 mm.	× 15 17 mm.	× 17 15 mm.	× 25 10 mm.
	Inches.	Mm.												
3230	1½	32	·15	4	25	45	65	—	110	4	6	8	—	15
3231	2/3	16	·28	10	62	110	155	—	270	8	12	18	—	30
3232	1/3	8	·5	18·5	115	200	285	—	500	20	30	40	—	75
3234	1/6	4	·85	45	285	490	690	—	1225	40	60	80	—	150
3235	[1]1/8	3	·95	60	427	735	1035	—	1837	50	85	120	—	210
3236	[1]1/12	2	1·3	90	530	900	1275	—	2250	60	100	150	—	250

List of Standard Apochromatic Object Glasses

					× 6 42 mm.	× 8 30 mm.	×11 22 mm.	× 17 15 mm.	× 25 10 mm.	× 6 42 mm.	× 8 30 mm.	× 11 22 mm.	× 17 15 mm.	× 25 10 mm.
3240	1½	40	·16	3	20	27	37	56	83	3	4	5	8	12
3241	2/3	16	·35	10	62	90	120	175	270	8	11	15	23	30
3241A	2/3	14	·35	13·5	84	120	160	215	365	12	16	22	34	50
3242	1/3	8	·65	21	115	155	220	325	500	20	26	35	60	75
3244	1/6	4	·95	45	285	380	540	805	1225	40	53	76	110	150
4345 [2]	1/6	4	·95	45										
3248	[1] 1/12	2	1·3	90	530	705	1000	1505	2250	60	80	110	170	250

[1] Oil immersion.

[2] This 1/6 has a correction collar for cover glass thickness.

become dirty, and in most cases the dirt will be on the front surface. This should be cleaned with soft silk or very soft chamois leather, but it must always be remembered that dust consists in many cases of hard particles, often harder than glass, and if these are rubbed upon the surface of the lenses they will leave fine scratches. Hence the correct method is to wipe very gently and so to remove the small particles and not to grind them on to the surfaces.

Removing oil from immersion lenses.

The lens which requires most cleaning is the front of an oil immersion, which is necessarily continually covered with cedar-wood oil. The oil should always be removed when the lens is put away after use. Oil can be removed with xylol, benzol, or spirits of wine, but care should be taken not to use too much of this liquid, so that there is no danger of its getting into the interior of the lenses. A piece of filter paper or blotting paper moistened with xylol or benzol and lightly wiped over the front surface will remove the oil without rubbing.

Keeping object glasses.

It is advisable to keep object glasses in the dust-tight metal boxes in which they are supplied when they are not in use. They will be safe except in a very moist atmosphere in a dust-tight nosepiece or in the boxes of the Sloan object glass changer. If object glasses show dirt on the interior surfaces or any other defects, they should be returned to the manufacturers, who alone can satisfactorily put these matters right and see that the lenses are in adjustment. High-power object glasses can be put out of order by the slightest error in putting the component lenses together. If a piece of dirt prevents one of the cells from screwing quite home, it is sufficient to destroy its performance. An object glass on the table when not in use should always be stood with its front lens upwards to prevent dust from accumulating on its back surface.

Corrections of object glasses.

The reasons for constructing an object glass out of a number of separate lenses in order to correct its aberrations will be discussed in a more complete treatise referred to in the preface, but one characteristic of a corrected lens should be thoroughly grasped. Any lens or combination of lenses can be made to form an image of an object at many different positions. If a lens, such as a bull's-eye, be put in front of a lamp, it can be moved to and fro from the lamp till a position is found where it will form a picture of the lamp on a wall ten feet away. If a card be now interposed at a distance of only two feet from the lamp, a slight movement of the lens away from the lamp will form the picture upon the card instead of the wall. In the same way, if the length of the drawtube of a microscope be altered, a slight movement of the object glass will bring the image which it forms to the correct position for the eyepiece to render it sharply defined. Any two positions where an object and its image are situated are called

a pair of conjugate foci. The important characteristic of an object glass is that it can only be absolutely correct for one pair of conjugate foci which, as applied to the use of the microscope, means that at one length of drawtube (160 mm.) the image will be clearer than in any other position. It is a point that is sometimes considerably exaggerated by writers on the microscope, who give the impression that if the wrong length of drawtube is used, the object glass is almost as bad as an uncorrected lens. The truth is that, especially with high-power lenses used with high eyepieces, for examining the finest details it becomes a factor of importance; but with moderate power eyepieces for general observation, a considerable variation of the length of tube makes no noticeable deterioration in the sharpness of the picture and forms an exceedingly useful means of altering the magnifying power. Low-power lenses, on account of their smaller aperture, are much less sensitive to a change in the length of the drawtube, and when using the 1½-inch (40-mm. and 32-mm.), 2/3-inch (16-mm.), or even 1/3-inch (8-mm.) object glasses with eyepieces not higher in power than × 10, a variation of 30 or 40 mm. in the drawtube is difficult to notice. With 1/6-inch (4-mm.), 1/8-inch (3-mm.), 1/12-inch (2-mm.) object glasses, it is best to use the standard 160-mm. tube length, and if a 1/3-inch (8-mm.) is being used with high eyepiece, the drawtube should be set at its correct length.

Conjugate images.

Tube length correction.

The other important factor in the best performance of an object glass is the thickness of the cover glass which is between the object and the front lens. With high-power lenses, the thickness of this cover glass has a far greater effect on the quality of the image than the length of tube.

Thickness of cover glass.

If a cover glass be used which is incorrect it can be corrected to some extent by making an alteration in the length of tube, and the following table gives the approximate amount of alteration in the tube length required to correct a variation in the thickness of the cover glass with different powers. An oil-immersion lens is not subject to this variation because it has nothing but glass, or its optical equivalent, between the object and the front lens. If the cover glass is thicker, the cedar-wood oil is proportionately thinner. For this reason the table only refers to dry lenses. It will only enable corrections to be made for cover glasses which vary between certain limits. For instance, a 1/6-inch cannot be corrected for an uncovered object by its means. The low-power lenses are so insensitive to small amounts of variation that the table is chiefly of use in indicating that the thickness of cover glass is unimportant except when working through thick troughs of water. It should be remembered that water has only about two-thirds the effect of glass, and, therefore, where a trough is used, one-third may be added to the figures given.

Correction of cover glass thickness by drawtube.

Table of drawtube corrections.

Length of Drawtube.	140 mm		150 mm.		160 mm.		180 mm.		200 mm.		240 mm.	
	Corresponding Cover Glass Thicknesses.											
	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.
1½ in. (32 mm.)[1] .	·200	5	·140	3·5	·100	2·5	·070	1·8	·040	·1	—	—
2/3 in. (16 mm.)[1].	·100	2·5	·085	2·1	·070	1·8	·050	1·3	·030	·08	—	—
1/3 in. (8 mm.)[1] .	·018	·46	·012	·31	·007	·17	·004	·1	—	—	—	—
1/6 in. (4 mm.) .	·008	·2	·0074	·19	·007	·17	·006	·15	·0053	·135	·004	·1

[1] The lower power lenses selected for the purpose of compiling this table are not as usually supplied, but are specially corrected for longer tubes to show the variation better.

Canada balsam acts in a similar manner to glass, and a layer of Canada balsam between the cover glass and the object has the effect of increasing the thickness of the cover glass. It must be allowed for unless the object is mounted in contact with the under-surface of the cover glass.

Correction of cover glass thickness by observation.

It will occur to the reader that the correct tube length can be ascertained by observing the image through the microscope. This is very readily done under dark-ground illumination, and with more difficulty with transmitted light. Under dark-ground illumination there will always be fine specks of dust illuminated as brilliant points; one which is so small as to show no apparent outline or shape should be selected and be placed near the centre of the field of view. It should then he focussed backwards and forwards, and the image examined on each side of the sharpest focus. If the light is all coming to an exact focus at any one point, the appearance on each side of the focus will be the same: it will be a small disc or patch of light equally intense

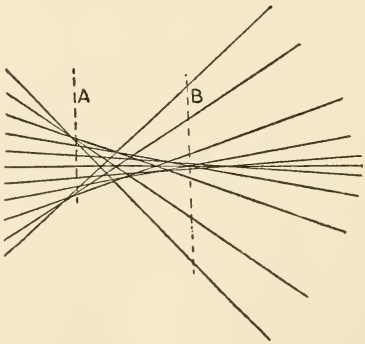


Fig. 89.

on either side. If it is out of adjustment, one side will be clear and the other side hazy. Fig. 89 shows that if all the light

from the object glass is not coming to the same point, the illumination will not be equally distributed at the two positions (A and B). It is important to select a very small point for the purpose, because many of the objects seen through the microscope are partially or completely transparent, and often globular, and act as small lenses themselves, which interferes with the phenomenon unless they are extremely minute. With transmitted light on a bright field the same plan may be adopted, but it requires much more careful observation because the image of a fine speck of dust when out of focus appears as a faint patch on a bright field, and is not so easily observed as a bright patch on a dark background. High-power eyepieces should always be used for making these observations. By the examination of insects' scales and diatoms much greater accuracy can be obtained in this adjustment, but the explanation of their use requires further discussion of the theory of the microscope and is not attempted in this book.

All high-power dry object glasses are made for use with a cover glass ·006 inch (·15 mm.) or ·007 inch (·17 mm.) thick unless specially ordered to be made for use without cover glass for polished metal specimens. The 1/6th-inch (4-mm.) is sometimes made with a correction collar, which is an adjustment which, by altering the distance between the component lenses, enables the object glass to be corrected for any thickness of cover glass between 0 and ·01 inch (·25 mm.). Such a lens in the hands of a beginner should always be used with its correction collar set at about ·007 inch (·17 mm.) unless no cover glass is being used. It may be a positive disadvantage to use such an object glass unless the microscopist is practised in the method of making the adjustment.

Correction collar.

The colour correction of an object glass is referred to later, but it should be remembered that an achromatic object glass can sometimes be slightly improved by the use of a colour screen, as such lenses always give a slight indication of faint colour. The faint colour effects often seen in transparent objects are, however, frequently due to the objects acting as small uncorrected lenses themselves, or to diffraction effects.

The flatness of field of a microscope depends on the object glass and the eyepiece combined. The edge is generally not in focus at exactly the same position as the centre of the field. Such a defect cannot be entirely cured in the best lenses, because to do so would sacrifice the finest definition in the centre; consequently, for the most exact examination the object must always be brought near to the centre of the field. With low-power lenses the defect is not so apparent, but with high powers there is always a marked superiority in the performance near the centre.

The following table gives the approximate sizes of the field

Sizes of field.

of view with various object glasses at the standard tube length, and the working distance of each lens.

Object Glasses.	× 6.	× 10.	Eyepieces, × 15 Field of View.	× 17.	× 25.	Working Distance, × 10 Eyepiece.
	in.	in.	in.	in.	in.	in.
1½ in. (40 mm.)[1] .	·25	·16	·115	·11	·1	2·05
1½ in. (32 mm.) .	·2	·11	·09	·085	·075	·88
2/3 in. (16 mm.).	·08	·045	·035	·032	·03	·25
2/3 in. (16 mm.)[1]						·11
2/3 in. (14 mm.)[1]	·07	·04	·03	·028	·025	·07
1/3 in. (8 mm.) .	·045	·025	·02	·019	·015	·06
1/3 in. (8 mm.)[1].						·037
1/6 in. (4 mm.) .	·02	·01	·0085	·0083	·007	·024
1/8 in. (3 mm.) .	·015	·008	·0075	·0065	·006	·016
1/12 in. (2 mm.).	·0085	·005	·004	·0038	·0035	·01

[1] Those marked [1] are apochromatic. The other object glasses are achromatic.

Standard screw of object glasses.

All object glasses are now made with a screw standardised by the Royal Microscopical Society; its specification is as follows:

Thread, Whitworth Screw, 36 to the inch, length ·125 inch.

Plain fitting on object glass above screw, ·1 inch long, ·759 inch diameter.

Diameter of thread of object glass at top of thread, ·7952 to ·7982 inch.

Diameter of thread of object glass at bottom of thread, ·7596 to ·7626 inch.

Diameter of thread of nosepiece at top of thread, ·7644 to ·7674 inch.

Diameter of thread of nosepiece at bottom of thread, ·8 to ·803 inch.

The stem of all the Beck object glasses are of a standard diameter, ·65 inch.

Variety of object glasses required.

The series of object glasses mentioned in this book is sufficiently large to cover all the requirements of microscopy, with the possible exception of a very low power for examining unusually large objects. The highest power is a 1/12th inch. It has sufficient magnifying power to show all the detail that the maximum aperture will resolve; and although object glasses of higher power can be made, they cannot be made with this maximum aperture because the lenses must be much smaller, and as a fixed distance must be allowed for a cover glass they cannot collect as large an angle.

Object glasses of imtermediate sizes have also been made from time to time, but the magnifying power given by an intermediate size can be so readily obtained by a change in the eyepiece that they are of little advantage. The manufacture of

object glasses has, therefore, been limited to a somewhat more restricted number of sizes than was customary some years ago, with considerable advantage, as concentration on the smaller number of lenses has tended to improve their quality.

Achromatic object glasses.

There are two types of object glasses, achromatic and apochromatic. Both types are excellent, and although there is no doubt that the apochromatic series possess qualities which render them of greater service where the most exacting scientific investigation is being carried out, for the more general work this extremely high quality of optical construction is not required. Hence the achromatic series fill the requirement for most purposes, and are in more universal use, on account of the fact that they can be made to a simpler formula and with a less number of component lenses and less expensive materials. The resolution of the achromatic lenses is of a very high order. As an example of their good performance, the diatom "Pleurosigma Angulatum" has dots in its structure which are approximately 1/48000 of an inch apart. The theoretical aperture which will show these as separate dots is ·5 N.A. This can be done with a Beck 8-mm. achromatic object glass which has this aperture (·5 N.A.), showing that an ordinary achromatic object glass, if properly constructed and adjusted, is so perfectly corrected for its zonal and other aberrations that it will resolve up to its theoretical limit. On a Grayson's ruling this lens will resolve 45,000 lines to the inch with a green screen and 50,000 with a blue screen. For visual purposes with a colour screen, achromatic lenses can be made almost optically perfect, but the apochromatic series described later are more perfect as regards their colour correction, are better for photography, have somewhat larger aperture, and will, therefore, stand the use of higher eyepieces, giving a slightly better defined image, especially when a colour screen is not employed.

Apochromatic object glasses.

The chief feature of the apochromatic series is that different glasses are employed and other materials substituted, and that this combined with a different formula, involving the use of a large number of component lenses, produces an object glass in which there is more perfect correction for chromatic aberration. In the achromatic object glasses the correction is made for two colours of the spectrum, but in apochromatic lenses this correction is made for three colours. For very fine markings undoubtedly apochromatic object glasses give superior results; the difference is slight, but the perfection of the colour correction enables certain objects to be seen with a greater crispness than is possible with achromatic lenses. Although the achromatic are suitable for photographic work, the apochromatic series has an advantage. For those interested in the optical construction of these lenses, we append a somewhat technical note on the theory of their construction.

It is a well-known fact that glass refracts the various colours by a different amount, and consequently a single lens will not give an image free from colour because it has different foci for different colours, the focus for red in a positive lens being further from the lens than the focus for blue. This property of refracting colours by a different amount is called the dispersion of the glass. From the time of Newton to that of Dolland it was supposed that the dispersion of different glasses was proportionate to their refractive powers (μ–1), and therefore proportionate to their foci. In other words, it was thought that any positive and negative lenses which had the same effect on the colour must have the same effect on the focus whatever glass they were made from, and that combining two such lenses would give the effect of a plain piece of glass without any focus. Conversely, they supposed that any combination of lenses which had a focus must have a colour aberration equal to a single lens of that focus.

In the middle of the eighteenth century Dolland discovered that this was not so, and that whilst the flint then is use had as compared with the crown glass a refractive power of 60 to 50, it had a dispersive power of 60 to 36.

If we take a crown glass of 1·5 refractive index, the difference in focus between the pale yellow or C-rays, and the green or F-rays, is about 1/60 of the focus; but if we take a flint glass of about 1·6 refractive index, the difference between the corresponding rays is about 1/36 of the focus. Therefore, if we take a positive lens of crown glass which is 36 inches focus, and a negative lens of flint glass which is 60 inches focus, the colour will be corrected for these two rays when the two lenses are put together, and the result will be an achromatic lens of 90 inches focus.

Although in this combination the two rays C and F would be correct, it would not give a perfect correction for the other parts of the spectrum, because the refractive power of the two glasses is not quite regular for the different colours.

For instance, the four coloured rays known by the spectrum lines C, D, F, and G do not have proportional dispersions; if we call the dispersion from C to F 1,000, we find that in a hard crown the distance from C to D is 295, and from F to G 568, whilst in a medium flint the distances are respectively 285 and 608. This may be expressed in the following manner.

	C—to—D	D—to—F	F—to—G
Hard crown . . .	295	705	568
Medium flint . . .	285	715	680

In this figure the lines at C and F coincide, but those at D and G do not, and the want of coincidence at D and G gives an idea of the secondary error.

If we make a pair of lenses out of these two glasses which when combined together give an achromatic lens of 1 inch focus, and correct for C and F, we find that the foci for the different rays are :

C	1·00000
D	·99963
E	1·00000
G	1·00165

In all kinds of optical glass with high dispersion the relative dispersion from F to G is higher than those of low dispersion, but in some the difference is slight, and telescope lenses with reduced secondary spectrum can be made from these. By combining three glasses together apochromatic telescope object glasses can be made, but in these the lenses have to be of relatively short focus, and consequently only small apertures compared to a microscope object glass can be obtained; *f*/6 is a very large aperture for a telescope object glass, but only corresponds to ·07 N.A. in a microscope object glass. No apochromatic microscope object glasses have yet been made satisfactorily by this means.

The peculiar mineral fluorspar, however, has totally different properties. It has a low refractive index and an extremely low dispersion about 1/95 on the focus. The great peculiarity, however, is that it has a larger proportional dispersion from F to G than many of the glasses with higher dispersion; the corresponding figure being 583. Now if we make a similar diagram to the last, but of fluorspar and light baryta flint, we get :

	C——to——D	D——to——F	F——to——G
Fluorspar . . .	296	704	583
Light baryta flint . .	296	704	570

A combination made of these two materials and achromatic, of 1-inch focus, gives the following results for foci of different colours :

C	1·00000
D	1·00000
F	1·00000
G	·99947

Now it is quite evident that combining with this combination another combination such as the first, in which the aberration for F to G is in the opposite direction, it is possible to produce a lens in which all the foci for the four rays are the same.

In practice the matter is more complicated than it appears, because the thickness of the lenses not only alters their foci but also slightly alters the ratio of their partial dispersions, and this has to be allowed for to get the corrections accurate.

In achromatic object glasses it is usual to correct for about C to F; this means that when correct visually there is a very slight error for D; but these can be neglected for most work, but for photographic purposes the error in G might be appreciable unless a coloured screen is used.

In apochromatic object glasses the colour is corrected for at least three parts of the spectrum, and also the spherical aberration is much more fully corrected for all colours; this means the lower power lenses have decidedly larger apertures than the corresponding achromatic lenses and that with all apochromatic object glasses higher eyepieces can be used. Also, when it is important to distinguish between objects with slight differences of colour, these lenses are much to be preferred.

Characteristics of Object Glasses of Different Powers

1½-inch object glass.

The 1½-inch (40-mm. or 32-mm.) object glass gives a maximum field of view ·2 inch (5 mm.) and has a working distance of ·88 inch (22 mm.) in the achromatic, or 2·05 (50 mm.) in the apochromatic series. It is, therefore, specially useful for obtaining a general view of large entomological and botanical specimens. It is the only object glass with which opaque vertical reflectors of the type of the Sorby flat silvered mirror, or the parallel flat glass mirror, can be used between the front of the object glass and the specimen, and is, therefore, useful for low-power metallurgical specimens. Its aperture (·16 or ·17 N.A.) gives a theoretical resolution of 15,000 to 18,000 lines to the inch, according to the colour of the light employed.

2/3-inch object glass.

The 2/3-inch (16-mm. or 14-mm.) object glass gives a maximum field of view of ·08 inch (2 mm.). The achromatic 16 mm. has a working distance of ·25 inch (6¼ mm.). The apochromatic 16 mm. and 14 mm. have working distances of ·11 inch (3 mm.) and ·07 inch (1¾ mm.) respectively. This is the power that is the most useful all-round low-power lens for every purpose. It forms a useful finder for searching specimens to be examined later with a high power. It can be used with the parabolic reflector for opaque objects, and is probably used in larger numbers than any other lens. The aperture of the achromatic (·28 N.A.) gives a theoretical resolution of 25,000 to 30,000 lines, and of the apochromatic ·35 N.A., 30,000 to 36,000 lines to the inch.

1/3-inch object glass.

The 1/3-inch (8-mm.) object glass gives a maximum field of view of ·045 inch (1¼ mm.). It has a working distance of about ·06 inch (1½ mm.). It is a medium-power lens of the greatest use for many purposes, and is not sufficiently appreciated. For

bacteriological and pathological investigation it can be used to do a great deal of the work for which two object glasses are usually employed. With a low-power eyepiece it has a field of view large enough for searching, and with a high-power eyepiece it can be used for blood counts and recognising micro-organisms such as trypanosomes, malaria parasites, and bacteria, and for pond life it is perhaps the most useful all-round power. For metallurgy it is an excellent lens for photography, and with this lens and an oil-immersion lens a microscopist can frequently do all his work in certain branches of research. This lens is particularly useful for dark-ground illumination with a substage condenser and patch-stops. The achromatic with an aperture of 5 N.A. gives a theoretical resolution of 48,000 to 52,000 lines, the apochromatic of ·65 N.A. about 62,000 to 67,000 lines to the inch.

1/6-inch object glass.

The 1/6-inch (4-mm.) object glass gives a maximum field of view of ·02 inch (1/2 mm.) and has a working distance of ·024 inch (1/2 mm.). It is the universal high-power, and when only two lenses are supplied, for cell-structure, histology, and all general high-power purposes, it is more popular than any other lens, and being made in large quantities is moderate in price. The achromatic has an aperture of ·85 N.A., the apochromatic ·95 N.A., and theoretical resolving powers of about 81,000 to 88,000 lines and 90,000 to 100,000 lines to the inch respectively. The very large aperture of the apochromatic lens of this focus and its perfect corrections renders it specially valuable for use with high eyepieces when an oil-immersion cannot be used. In this case the 1/6-inch with a correction collar should be selected, and the microscopist should become familiar with the correct adjustment of this collar (see page 80).

1/8-inch object glass.

The 1/8-inch (3-mm.) oil-immersion object glass has a maximum field of view of ·015 inch (·375-mm.) and a working distance of ·016 inch (·4-mm.). Being an oil-immersion lens, it is not affected by the thickness of the cover glass used, and is thus always working at its best. It is introduced not because a power between a 1/6-inch (4-mm.) and a 1/12-inch (2-mm.) is often required, but because a special lens with a maximum aperture that can be used with dark-ground illumination is urgently required for this work. As explained in the description of the use of the dark-ground illuminator, a large aperture oil-immersion lens such as a 1/12-inch (2-mm.) 1·3 N.A. must be stopped down to the aperture of a 1/6-inch (4-mm.) dry lens to enable it to be used with dark-ground illumination, and resolving power is thus lost. The 1/8-inch (3-mm.) object glass can also be used to do most of the work with one object glass that is generally done with the 1/6-inch (4-mm.) and the 1/12-inch (2-mm.). It has an aperture of ·95 N.A. and a theoretical resolving power of 90,000 to 100,000 lines to the inch.

1/12-inch object glass.

The 1/12-inch (2-mm.) oil-immersion object glass has a maximum field of view of ·0085 inch (·2 mm.) and a working distance of ·01 inch (1/4 mm.). This is the high-power lens which must be used, if it is necessary to see the finest detail which can be observed with any microscope. It has an aperture of 1·3 N.A. and a theoretical resolving power of 125,000 to 135,000 lines to the inch. It is the object glass that reaches the highest limit yet obtained in microscopic vision, and is a necessary portion of a complete outfit. The apochromatic, being slightly better than the achromatic, is worth the extra cost even if all other lenses are of the achromatic series. If structure of an object is just beyond the limit of vision of a low-power, a higher power object glass can be used; but this does not apply to a 1/12-inch, as no higher power will show more; and if the quality of the highest power lens is such that even slightly higher power eyepieces can be employed, the scope of the instrument is extended.

Eyepieces

Huyghenian Eyepieces

No.	Focal Length.	Magnifying Power.
3260	42 mm.	× 6
3261	25 mm.	×10
3262	17 mm.	×15

Compensating Eyepieces

3266	45 mm.	× 6
3267	30 mm.	× 8
3268	22 mm.	×11
3269	15 mm.	×17
3270	10 mm.	×25

Standard size.

All eyepieces are made to the diameter of the Royal Microscopical Society's No. 1 Standard Drawtube, ·917 inch diameter. They are made to drop in loosely, so that they may be changed without any tendency to alter the adjustments of the microscope. They are designated by their focal length, and their magnifying power is given for the distance of distinct vision—10 inches (250 mm.)—and is engraved on each eyepiece.

Best eyepieces for general work.

The best eyepieces to use for general work are those of the lowest powers, 42 or 45 mm. and 25 or 30 mm. The eyepoint (T, Fig. 1, page 9) is large with low-power eyepieces, and fine specks of dust on the surface of the eye or in any part of the instrument do not readily show. The higher the power of the eyepiece used, the smaller is the diameter of the eyepoint, and any such minute obstacles to the passage of the light become more apparent. It is, however, of the utmost value to be able to slip in a high-power eyepiece for occasional examinations, in order to increase the power without altering the adjustment of the

instrument, and for this purpose a 17- or 15-mm. or a 10-mm. eyepiece is required. A 5-mm. eyepiece magnifying 50, and a 2·5-mm. magnifying 100, are made to order for special testing purposes, and have their uses.

Compensating eyepieces are specially corrected to work with apochromatic object glasses, and when of a higher power than 15 mm. are the best for use with achromatic object glasses. The difference in performance of the Huyghenian and the compensating eyepieces is not very marked. Compensating eyepieces.

Huyghenian eyepieces consist of two plano-convex lenses, one at each end of a tube, with a diaphragm between them. It is an eyepiece that has many advantages for visual work, but it is not the best for photography. It is also not quite so perfectly corrected as the compensating eyepieces which are specially made for work with apochromatic object glasses. The lower of the two lenses is called the field lens, because it increases the size of field while the upper one does the magnifying. The two lenses are of such powers and placed in such positions that they are achromatic and give a fairly flat field for visual purposes, but do not do so for photography, where the microscope has to be re-focussed in such a manner that an actual image is formed behind the eyepiece instead of a virtual image projected in front of the observer's eye. Huyghenian eyepiece.

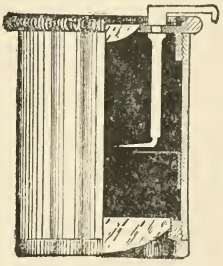


Fig. 90.

The corrections of an eyepiece need not be of so perfect a character as those of an object glass, because the individual bundles of rays from each point of the object are very narrow beams of light as they emerge from the eyepiece, and the defects of an eyepiece are reduced in a similar manner to those of an object glass when it is stopped down by a pinhole aperture. The aperture which limits the size of the beams of light is not a pinhole, but the same effect is produced by the narrow angled cones of light which come from the object glass.

The magnifying power of the eyepiece is never very great compared with that of the object glass, and it is only in those of high power that the corrections are of such importance that the extra quality of the compensating series are very noticeable, except for photography or where entire freedom from colour is essential.

The so-called projection eyepieces are no better for projection and photography than the compensating, and are far more difficult to adjust.

Eyepiece micrometers or plates of glass ruled with squares or cross lines may be dropped upon the diaphragm in the tube of the eyepiece by removing the cell holding the upper lens. By

screwing the upper lens cell up and down into the tube they may be sharply focussed (see page 67).

An eyepiece with a movable pointer in the field of view, an erecting eyepiece and a polarising eyepiece are described in pages 72 and 73.

The Selection of Object Glasses and Eyepieces

Advantage of complete set.

Where price is not an object, it is advisable to have a complete set of either achromatic or apochromatic object glasses, including only one of the 2/3-inch apochromatic and one of the 1/6-inch apochromatic. Each size has its special uses as previously described, and they do not overlap. It is best to have apochromatic object glasses and a complete set of compensating eyepieces. At a time when many intermediate sizes of object glasses were made, a selection was always necessary; now that they have been reduced to a smaller number of standard sizes, they are all of great assistance to any observer. It is not, however, every microscopist who can afford to buy a complete set, and in this case the selection becomes a matter of importance. For work on all subjects, all sizes will probably be eventually required, though they need not be purchased at once.

Histology and pathology.

For histological and pathological work, the student is advised by his teacher to purchase a 2/3-inch (16-mm.) and a 1/6-inch (4-mm.) object glass and two eyepieces magnifying $\times 6$ and $\times 10$, adding a 1/12-inch oil-immersion for pathological work at a later date. It is a question whether in some cases he might not do better to start with a 1/3-inch (8-mm.) and an 1/8-inch (3-mm.) oil-immersion, adding a $1\frac{1}{2}$-inch (32-mm.) for very low-power work if required. In such a case he should have three eyepieces, $\times 6$, $\times 10$, and $\times 15$, as the highest power eyepiece enables a great deal of work to be done with the 1/3-inch (8-mm.) that would generally be done with a 1/6-inch (4-mm.). The 1/8-inch (3-mm.) oil-immersion is a very useful power. The 1/3-inch (8-mm.) is only slightly affected by the thickness of the cover glass, and the 1/8-inch oil-immersion is not affected at all, so that the unskilled observer is more likely to get the best out of his instrument with these two powers. The addition at a later date of a 1/12-inch apochromatic object glass and a high-power compensating eyepiece makes a very perfect outfit. Where price is of great importance, the cheapest outfit will be a 2/3-inch (16-mm.) and 1/6-inch (4-mm.), as usually recommended.

Biology.

For biological work the same remarks apply to a great extent, but the 2/3-inch (16-mm.) has the great advantage that, used with an erecting eyepiece, it turns the instrument at once into a dissecting microscope. It is also sometimes troublesome to use an oil-immersion with an unmounted specimen examined in water under a cover glass, and a high-power dry lens is often preferred.

The difficulties of using an oil-immersion lens, however, chiefly apply to cases where it is necessary to search with a low power, change to a high power, and then rapidly search again, as in the latter process the oil must be wiped off the cover glass with a piece of filter paper dipped in benzol or xylol before the low power is used. The 1/6-inch dry apochromatic with a cover glass adjustment is a very useful lens for such work, because it has a very large aperture and resolving power, and if carefully adjusted for the cover glass thickness, owing to its very perfect corrections, can be employed with very high eyepieces to do much of the work that would otherwise be done with a 1/12-inch.

Botany. For botanical work the 2/3-inch (16-mm.) and 1/6-inch (4-mm.) are generally used by the student. A great deal of the work could be better done with 1½-inch (32-mm.) and 1/3-inch (8-mm.) with a higher eyepiece. A 1/12-inch oil-immersion may be added for cell structure, such as Karyokinesis.

Metallurgy. For metallurgical work the best three lenses are the 1½-inch (32-mm.), 1/3-inch (8-mm.) and 1/12-inch (2-mm.) oil-immersion. For photography the apochromatic series have a marked advantage, as colour screens need not be used; compensating eyepieces should always be selected for photomicrography as the Huyghenian eyepieces are not satisfactory for this purpose. For chemical and industrial purposes it is difficult to make any recommendation. The objects examined are so varied and the conditions so different that nothing but a complete series will meet every requirement. It is best to study the capabilities of each object glass as given on page 86, and select according to circumstances.

Petrology. For petrology the best two lenses are the 2/3-inch (16-mm.) and the 1/6-inch (4-mm.); the high-power dry lens being essential for observing interference figures, as a large aperture is necessary for this work. A low-power 1½-inch (32-mm.) is very useful. The apochromatic series must be used with caution for this purpose, the fluorspar of which they are made may render them unsuitable in some cases.

General recreation. For general recreation the whole series will appeal to the microscopist who wishes to dip into a large number of subjects. If only two object glasses are required he should begin with a 1½-inch (32-mm.) and a 1/3-inch (8-mm.) and three eyepieces.

CHAPTER VI

THE MICROSCOPE STAND

Essential qualities.

In all microscopes certain characteristics are important. The quality of the optical portions is the essential, but the stand requires to possess good adjustments and rigidity of construction to enable the optical qualities to be made full use of. Those who are not competent to judge of the optical performance may be sometimes tempted to criticise small details of mechanical construction which are of no importance, but certain main points are worthy of consideration.

Base and pillar.

The base and pillar of the microscope have been a subject of long discussion among microscopists. If the instrument is supported in a rigid manner, their shape and construction is not of great importance. Two chief types have been made, one of which has three projecting legs of varying shapes, the other consists of a flat slab with a pillar fixed upon its upper side. The former is generally known as the English model, and the latter as the horseshoe base. It was originally introduced more or less of the shape of a horseshoe, but has since been altered in its outlines. Both stands rest upon the table on three toes and, provided the distance apart of these toes is the same, the two models are equally rigid. The horseshoe pattern relies for its stability slightly more upon its weight than its size. It has the advantage that it can be used rather nearer the edge of the table when the microscope is in a vertical position, and that all the adjustment of the substage can be more readily got at than in the English model, where the side projecting legs are more or less in the way of the hands. It also requires a rather smaller case or bell-glass cover. Most microscopes are now made with the pillar and slab form of base known as the horseshoe, or with one piece that has a shape which approximates to a horseshoe base and pillar combined. Far too much time has been wasted in the past by arguing on the relative merits of the two forms. The microscope should stand rigidly and be free from any tremor in its parts. In cities or near machinery where constant vibration is present it is sometimes worth while to take special measures to overcome this. A slab of slate supported on a layer of cotton wool an inch thick will generally damp out vibration. In a

factory with rapidly-moving machinery, the microscope table may be placed on a stone which rests on an inflated motor-car tyre. Under ordinary circumstances such precautions are not necessary, and any firm table is satisfactory.

Stage. The stage should be firm and its upper surface should not be less than $4\frac{1}{2}$ inches above the table. An ebonite covering makes a better surface than metal for giving a smooth motion to the slide. It is less likely to be damaged by reagents, but a brass stage with a surface ground flat is very satisfactory. There should be a horizontal distance of not less than 3 inches between the optic axis or centre of the stage aperture and the limb to enable Petri dishes and large culture plates to be examined.

Body tube. The body tube must be of a variable length. The early microscopes were generally made with a 9- or 10-inch tube, but have been entirely superseded by the more compact type which has a tube length of 140 mm., which, by means of a drawtube, can be increased to 200 mm. The shorter tube length has an advantage in addition to the reduction in the size of the microscope of which it admits. In the previous chapter it has been explained how the variation in the thickness of the cover glass can be largely compensated by a variation in the length of the drawtube. A body tube of great length must be moved to a great extent to produce much alteration, while a short body is far more sensitive in this respect, and a much greater range of correction can be obtained. It is also possible by an extra tube to further lengthen a short body, while it is not feasible to shorten a long tube.

Drawtube. The drawtube should always be graduated in millimetres, which give the length at every position, and it should work with great smoothness, so that when the microscope is in use the length of the tube may be altered without exerting any force which is likely to upset the adjustment of the instrument. The sliding fitting should always be in cloth or other fabric which will ensure a smooth motion. A metal-to-metal slide is not so satisfactory; such a slide may be perfect when it leaves the makers' hands, but the slightest film of tarnish or oxidisation ruins its working and gives a jerky, uneven motion. Due to the elasticity of a thin cloth or a fabric slide, it cannot be quite as stiff and rigid as a metal slide, but this is a matter of no practical consequence, as a slight movement of the eyepiece out of the optic axis has no effect on the quality of the image. The drawtube must be provided with a diaphragm to prevent reflections at the inner sides of the tube, and the upper portion of the drawtube should be slightly smaller in diameter than the lower part, so that pushing the eyepieces in does not tend to polish the tube below the position where the shortest eyepiece fits. The lower end of the drawtube should have a screw fitting for the use of a low-power object glass.

Adjustments. The coarse and fine focussing adjustments must be well made

and must work with a smooth, even motion that allows of the most delicate setting for focus. The coarse adjustment should be capable of focussing with a 1/6-inch object glass, although after the focus has been found the slow motion will generally be used. It is an advantage to have a series of divisions on the slow motion by which the thickness of a cover glass or a section can be ascertained (see page 53). The value of the divisions is given under the description of different microscopes. The two adjustments should work in fittings which are made with the utmost precision. These fittings should be solid metal slides without any adjusting screws. The wear in the fittings of a microscope is infinitesimal compared with those of running machinery, and slides well fitted in the first instance will wear for a lifetime without adjustment if properly used. All kinds of adjustable fittings have been tried, but have been abandoned. The adjusting screws work loose, the slides do not have to be so well fitted originally, and nothing is so good as a solid slide well fitted in the first instance.

The milled heads of both the adjustments should move in the same direction, so that the upper portion of the milled heads is going away from the observer when the body tube is going down or approaching the object. Mistakes made by turning the milled heads in the wrong direction may result in breaking the slide or damaging the object glass. If all the milled heads in a microscope move in one direction, such mistakes need not be made.

Joint.

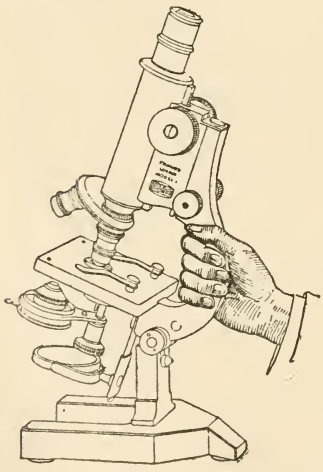


FIG. 91.

A microscope should have a joint for inclination. The instrument may have to be used occasionally in a vertical position, but it is so much more convenient in any other position that an inclining joint should not be omitted from the stand. The writer does all his most difficult tests and examinations with a microscope on an optical bench in an almost horizontal position, the axis pointing down only about 15°. The eyepiece is at the eye-height of the observer when in a sitting position. Prolonged observation of several hours ceases to be tiring with the microscope thus arranged. An ordinary microscope, however, inclined to about 45° is very comfortable for prolonged work.

Limb.

A microscope should have a limb that can be readily grasped by the hand for lifting. It must never be lifted by its body or

any of the adjusting milled heads. The only other portion of the instrument by which it may be lifted is the base or pillar. Valuable instruments may be badly damaged if lifted carelessly. Adjustment slides may be ruined, pinions and screws bent, or the entire instrument may be dropped if these instructions are not followed.

Mirror. A suitable size for the mirror of a microscope depends upon how far it is placed below the stage; a large mirror close to the stage is of no advantage. A 2-inch diameter mirror $3\frac{1}{2}$ inches from the stage will converge a beam of light at approximately 30°, and this is more than is ever required. When a substage condenser is employed, the mirror need not be much larger than the back lens of the condenser, which never exceeds $1\frac{1}{4}$ inches. A 2-inch mirror is, therefore, more than sufficient for all ordinary types of microscopes. A mirror should preferably be on a fitting by which its distance from the stage may be varied. It is not only of advantage for focussing the concave mirror, but enables very long apparatus to be used in the substage by sliding it farther from the stage than its usual position. It is convenient that it should be capable of swinging to one side for inserting substage apparatus or for using light direct from a source of illumination, but in use it must always be placed in the axis of the instrument.

All the microscopes illustrated in this book possess the features here described as being of importance; the following brief notes explain their special characteristics.

Except the special metallurgical and petrological microscopes, all the instruments illustrated are suitable for every branch of work. The highest class of research work calls for a mechanical stage and the best substage adjustments. The rack and pinion adjustment to the drawtube and the rotating stage are of considerable advantage, but are not essential.

Standard microscopes. The Standard London Microscope is illustrated in six forms. The first three of these forms are the same except as regards their substages. These microscopes fulfil the conditions given in previous pages as to the essential features which a serviceable microscope must possess. They have also many smaller advantages and refinements. The base consists of an iron casting of suitable weight to give rigidity to the instrument, encased in a covering of vulcanite which gives it a durable finish. It is of such a spread as to prevent the instrument from tipping, and is also made of such a shape that it can easily be fixed down to a bench when used for photomicrography when the instrument is used horizontally. This may be done with advantage, as it prevents the microscope from being moved during the process of attaching the camera. The joint of the instrument is stopped at the exact vertical and horizontal position. The stage consists of a brass core completely embedded in vulcanite. This method is more satisfactory than the usual method of fixing on thin vulcanite plate on the top of

The base.

The stage.

a brass stage, as it is less subject to warping, is not easily chipped or broken. The stage has four holes for the accommodation of stage clips. The limb is drilled with a hole by means of which a mechanical stage can be attached, held in position by a strong bolt with clamping milled head. This mechanical stage can be fitted by the user of the microscope without returning the instrument to the maker, although it is best to do so if possible, as in this case a steady pin is also put in to ensure that the mechanical stage is in its exact position, and thus to make certain that the finder divisions read correctly. The finder divisions read from the left-hand side and the bottom of the 3 × 1 slip. The standard body of the microscope is of rather larger diameter than is usual with the ordinary small body tube. The coarse adjustment is actuated by the upper milled head, and the fine adjustment by the lower. The fine adjustment is of rigid type and gives a very sensitive and smooth motion. It has two speeds, the left-hand milled head travelling the body at half the speed of the right-hand milled head. The substages are all interchangeable, and all the microscopes are supplied with the holes necessary for the fitting of any of the various forms of substage which can be attached by the user with the aid of a screw-driver. Thus a microscope with a plain tubular substage may first be bought, and if the microscopist at a later date feels the need of a substage with focussing and centring adjustments, this substage may be purchased separately, and he is able to fix it himself, without sending the microscope to the maker. The following are the dimensions of these microscopes:

The limb.

The mechanical stage.

The body.

The adjustments.

The substage.

Dimensions of the microscope.

Size of base	$6\frac{1}{2} \times 4 \times 1$	in.
Distance of upper surface of stage from table	$4\frac{3}{4}$	,,
The height of the microscope in use when vertical	$12\frac{1}{2}$	,,
The height of its optical centre when horizontal	$6\frac{1}{8}$	,,
Diameter of coarse adjustment milled heads	$1\frac{1}{2}$	,,
Diameter of fine adjustment milled heads	$\frac{7}{8}$	,,
Travel of coarse adjustment	$3\frac{1}{4}$	,,
Each division of the fine adjustment moves the body	·01	mm.
Travel of fine adjustment	6	,,
Diameter of object glass screw, Royal Microscopical Society's Standard	·8	in.
Diameter of drawtube, Royal Microscopical Society's Standard No. 1	·917	,,
Diameter of substage, Royal Microscopical Society's Standard	1·527	,,
Diameter of mirror	2	,,
Focal length of mirror	3·5	,,
Vertical travel of mirror	1·5	,,
Tube length	140 to 200	mm.
Outside diameter of upper portion of drawtube	1·05	in.
Diameter of object glass stem	·65	,,
Distance from optic axis to inside of limb	3	,,

No. 3210.

No. 3210, page 97, is the simplest form of the microscope, and has a plain tubular substage into which slides a fitting with

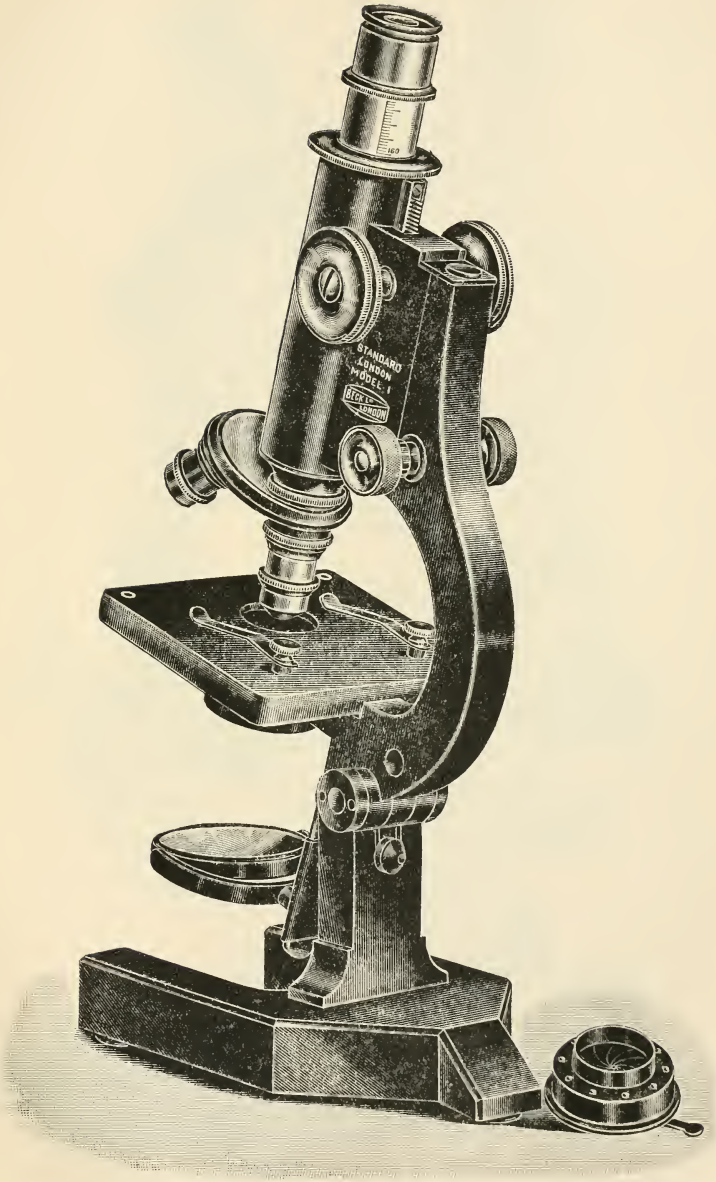


Fig. 92.—No. 3210, Standard London Microscope, with plain tubular substage and dust-tight double nosepiece.

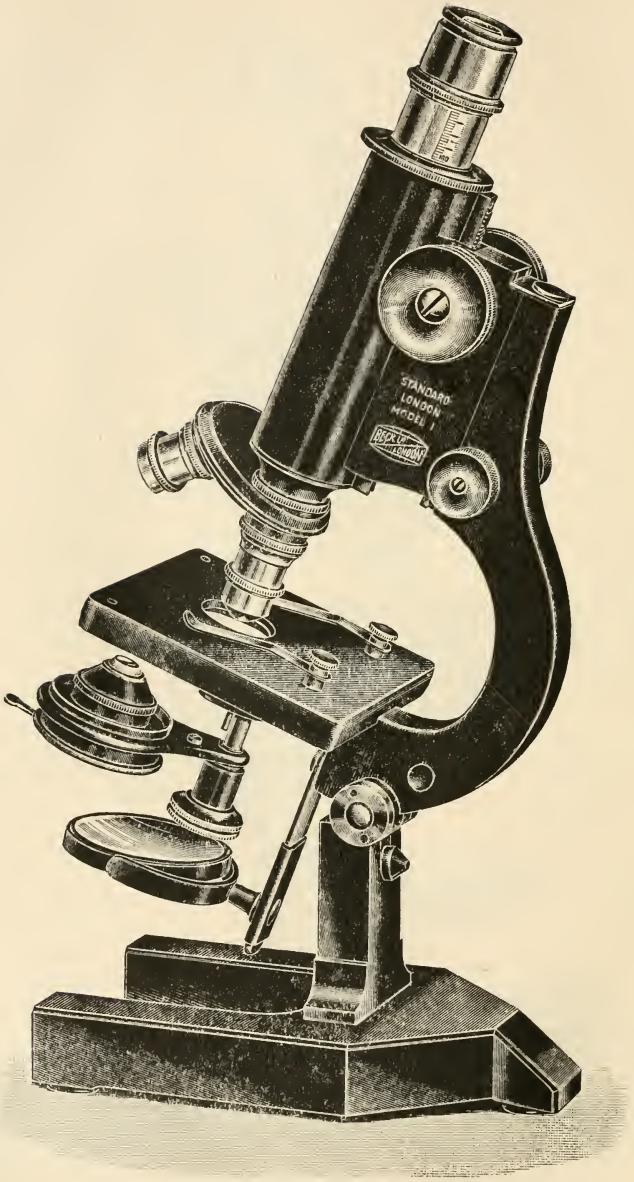


FIG. 93.—No. 3211, Standard London Microscope, with screw focussing swing-out substage, dust-tight double nosepiece.

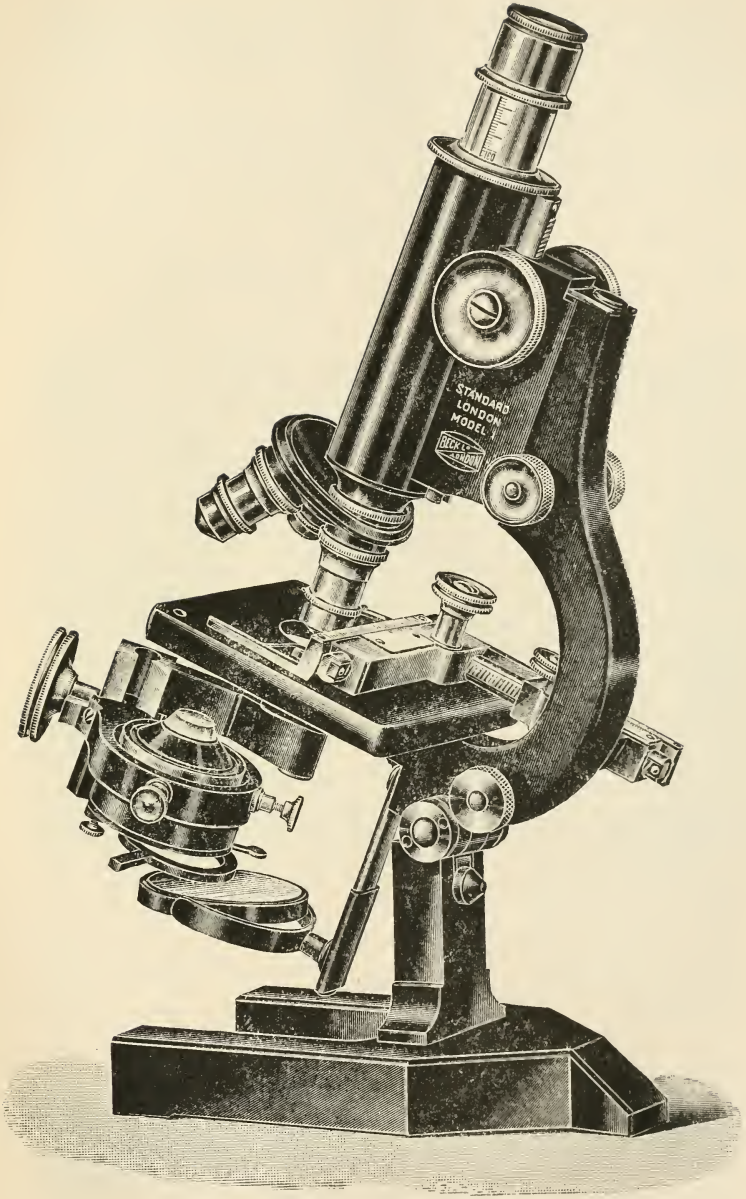


Fig. 94.—No. 3213, Standard London Microscope, with rack and pinion and centring swing-out substage, triple nosepiece, mechanical stage.

an iris diaphragm. In the upper cell of this a small Abbe condenser can be fitted, and also a series of patch-stops or a coloured or ground glass. The fitting can be moved up and down in the tube to a limited extent for focussing.

No. 3211. No. 3211 (page 98) has a substage which focusses by means of a screw actuated by a milled knob. When this screw reaches the end of its travel in a downward direction the whole fitting carrying the iris diaphragm and condenser swings aside, so that it is a very simple matter to entirely dispense with the condenser when it is not required. The substage is held rigidly in the optic axis until the fitting is focussed down to its lowest position, when a further turn of the milled head swings it out of position, thus the addition of this motion does not in any way affect the rigidity of the substage. This substage is suitable for use with either the small or large form of the Abbe condenser. Centring motions cannot be fitted, and it is consequently not suitable for use with an achromatic condenser. A high-power dark-ground illuminator can be used with it, but must be in a fitting that is provided with centring screws.

No. 3213. No. 3213 (page 99). This microscope has a substage with full adjustments—namely, focussing by rack and pinion, swing-out motion, and centring motion. The focussing is actuated by a large milled head on the right of the instrument travelling in the same way as the coarse adjustment milled heads. When at the bottom of its travel the substage may be completely swung aside. Here again, as this substage is held in position by a guiding pin, until it is in its lowest position, there is no tendency to lose rigidity by the addition of the swing-out motion. The centring is actuated by two screws with milled heads. A modified form of this stand, No. 3212, is made which is the same as No. 3213, except that the substage has not a centring adjustment. This is suitable when it is not desired to use a higher class condenser than the Abbe form, but for all more exacting work the No. 3213 is preferable. The substage on this stand No. 2313 enables the achromatic condenser and the high-power dark-ground illuminator to work to their full advantage. The illustration, page 99, shows this microscope with a detachable mechanical stage attached by bolt and nut, as mentioned previously.

The Portable Standard London Microscope

Portable microscope, No. 3221. This microscope has been designed for the use of the microscopist whose work requires that he should have an instrument of the usual rigid construction, with all the movements necessary for the highest forms of research work, but to whom portability is also an advantage. For travellers engaged in critical work, and bacteriologists in foreign countries, this microscope is especially suitable. The stand is the same as the standard

pattern No. 3213 except as regards the base and stage. The former is folding, and has the same spread as that of the standard model. The stage with the substage attached removes for packing into the case. It is so made that when in position it is even more rigid than the standard form. It is attached on a bracket and is held in position by a taper bolt. The substage has all the adjustments of the No. 3213, including focussing rack and pinion, centring by screws and a swing-out motion. The instrument is packed in a case which only measures $11\frac{1}{2} \times 8 \times 2\frac{1}{2}$ inches. It is as perfect an instrument in every way

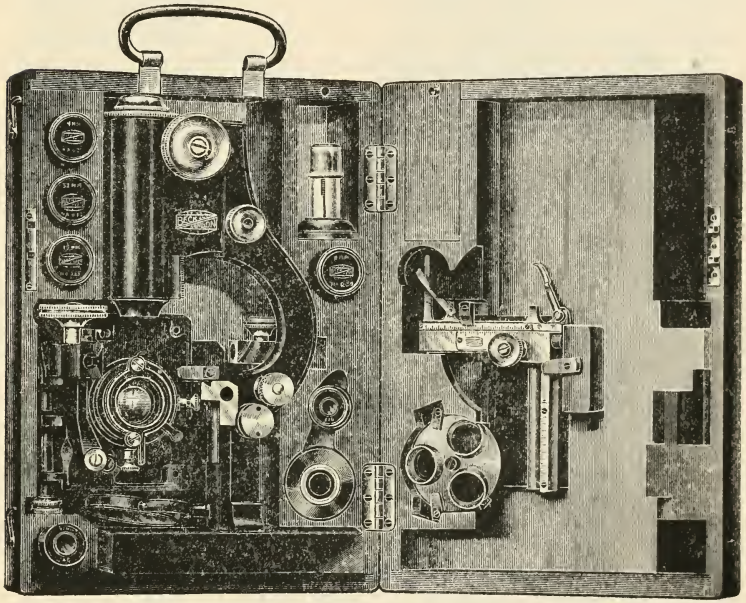


FIG. 95.—No. 3221, Portable Standard London Microscope in case.

as the ordinary model. The case will carry two eyepieces, three object glasses, substage condenser, dark-ground illuminator, a detachable mechanical stage, triple nosepiece, and a bottle of oil, together with a supply of slips, cover glasses, and sundry small apparatus. It does not weigh much less than the ordinary model. The small dimensions of its case render it specially suitable for travelling where a bulky instrument is inadmissible. It has no disadvantages due to its portability, and most standard apparatus can be fitted to it. For the ordinary microscopist who takes his instrument from place to place it is very convenient.

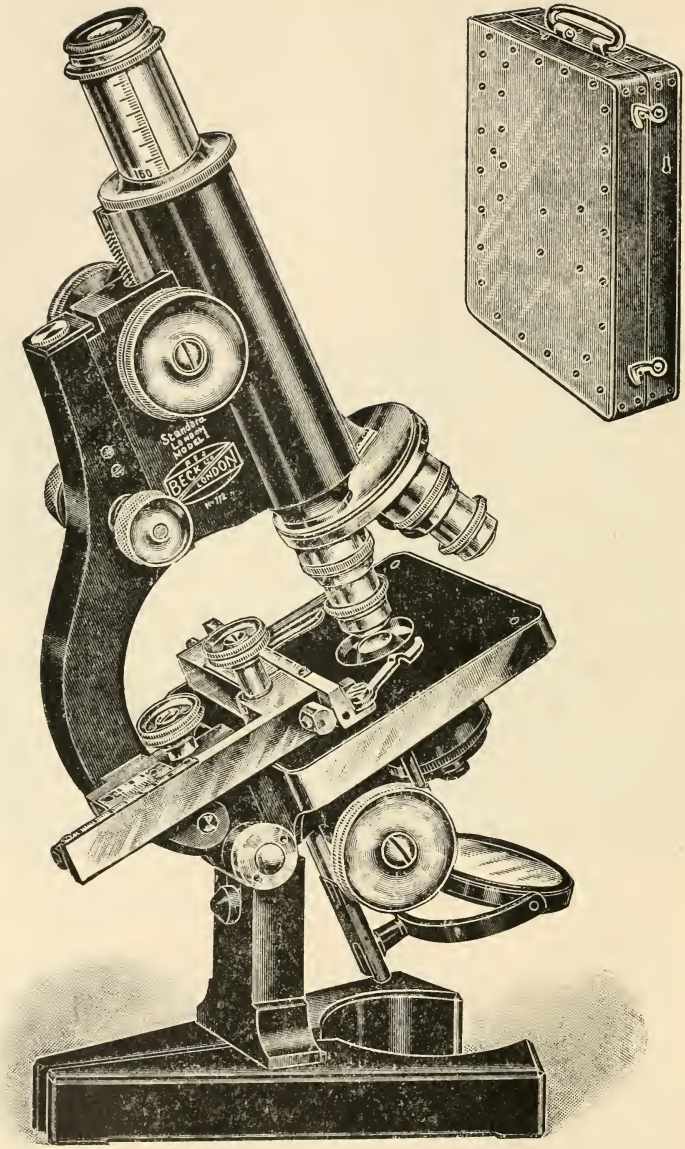
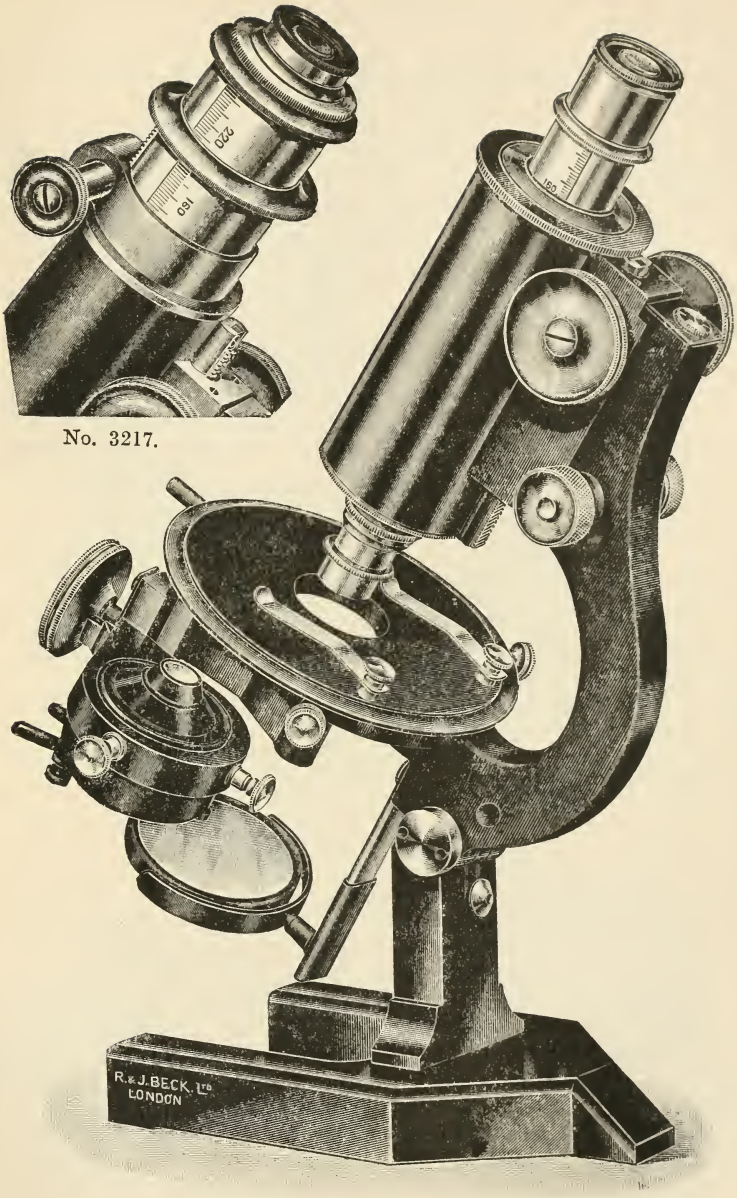


FIG. 96.—No. 3221, Portable Standard London Microscope, with rack and pinion, and centring substage, mechanical stage, triple nosepiece, and condenser.



No. 3217.

Fig. 97.

No. 3216, Standard London Microscope, with large body, circular stage, and complete substage adjustments.

No. 3217, Rack and pinion focussing and double extension draw-tube.

The Standard London Microscope with Circular Rotating Centring Stage

This instrument is made in four forms. No. 3214 has a screw focussing substage and is the same as No. 3211, page 98, with the addition of the circular rotating and centring stage.

No. 3215 has a rack and pinion focussing and centring substage and is the same as No. 3213, page 99, with the addition of the circular rotating and centring stage.

No. 3216 is the same as No. 3215, but with a large 2-inch body instead of the standard size. Both the nosepiece and the drawtube end of the body can be unscrewed, and a photographic lens can be slid into the centre of the tube for photographing large specimens. The large size body does not cut off the angle of view given by such a photographic lens. Also, if the drawtube end of the tube be unscrewed and the nosepiece left in position, low-power lenses with a large angle of view may be used in the nosepiece for a similar purpose.

No. 3217 is the same as No. 3216, but with a rack and pinion adjustment to the drawtube, and is provided with a second drawtube, enabling the length of the tube to be varied from 140 mm. to 250 mm. The drawtube is very large in diameter, and can be provided with extra large eyepieces, 1·41 inch diameter, of the No. 1 R.M.S. standard size.

The circular mechanical stage illustrated on page 52 fits any of these four models.

This microscope, with an interchangeable binocular body described later, makes a very perfect research microscope.

The Massive Model Microscope

No. 3201. There are certain cases in which most small microscopes give dissatisfaction for very delicate work, and this model was first made for The National Institute for Medical Research, who gave valuable assistance in the design and construction. It is intended for those who feel the want of a very perfect instrument. It has been made throughout on a very heavy and stiff design. It does not stand much higher than the standard model, but it is unusually strong and stiff, so that no vibration or flexure can take place. The limb consists of a massive brass casting which extends in one piece from the body to the mirror. The tail-piece and fine adjustment slide are planed out in one continuous cut so as to ensure the perfect alignment of the substage with the focussing adjustment. The stage, which is strengthened below by side ribs, is rigidly fixed on to the limb, so that it is as strong as a solid piece. It is of great advantage to have a stage so solid that it does not show movement under the highest powers by the weight

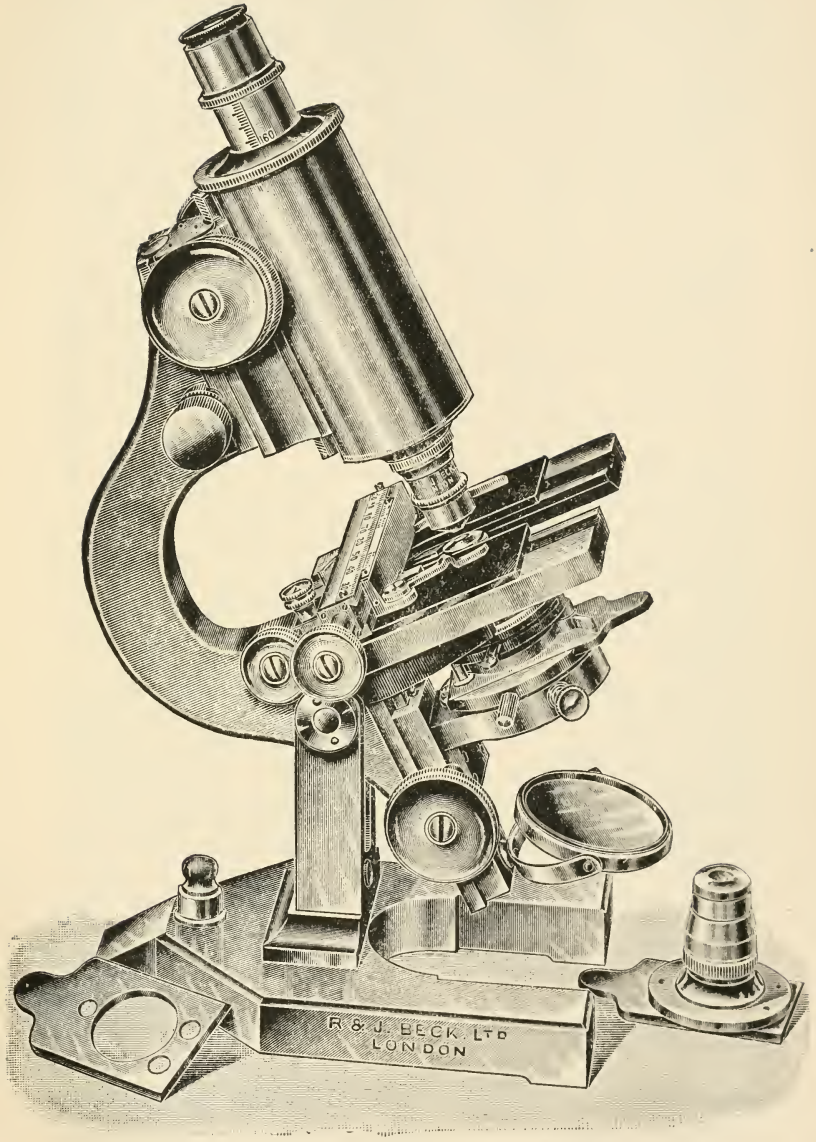


Fig. 98.—No. 3201, Massive Model Microscope.

of the hands placed even heavily upon it. The pillar and base are equally heavy and free from any spring. The fine adjustment is exceptionally delicate—one revolution of the milled head moves the body only ·1 mm. Each division on the milled head is equal to ·001 mm. The coarse adjustment milled heads are very large, enabling a finer adjustment to be made. The stage is square, measuring $4\frac{1}{2} \times 4\frac{5}{8}$ inches. In the simple model it is flat, with a gap cut out in front, and the standard mechanical stage can be attached to it at will in a similar manner to that of the standard model, being clamped to the limb through an aperture left for the purpose. When a mechanical stage is supplied at the same time as the microscope, it is fitted with a steady pin entering a second hole in the limb, so that it cannot be attached in an incorrect position. In the best form of instrument, as illustrated on page 105, the square stage has two dovetailed grooves planed in its surface, and the mechanical stage racks up and down these grooves or can be removed at will. This mechanical stage has its actuating milled heads projecting laterally on the right-hand side. The upper one moves the slide laterally and has 3 inches (75 mm.) travel, the lower one moves the slide vertically and has a travel of $1\frac{1}{4}$ inches (30 mm.). The latter motion is provided with a clamp screw, so that it can be locked to prevent any chance of the slide moving when the instrument is in a horizontal position. This prevents any settling down of the object during photomicrography. Verniers reading to 1/10 mm. are provided to both movements in convenient positions for reading.

The substage racks up and down on the lower portion of the limb, which is accurately in the optic axis of the microscope, and the mirror fits by means of a sliding fitting on the same slide. The substage has centring adjustments and is of the standard size, but at its upper end is fitted with a dovetailed fitting to receive the condensers or dark-ground illuminators. All the illuminators are mounted on dovetailed slides which slide easily into the dovetailed fitting, and are held accurately in position by a clamping milled head. Each illuminator is accurately centred and of the same length, so that they can be rapidly interchanged while the object is under observation. The front portion of the stage is cut out to enable this to be done, and even an oil-immersion condenser can be changed for a dark-ground illuminator while the slide is under observation. While these illuminators are in use, the tubular portion of the substage is free to receive apparatus which can be used in conjunction with them. The back of the foot of the microscope carries a short vertical post, and when the microscope is placed in a horizontal position for photomicrography this takes the weight of the limb and makes a rigid support under conditions where a slight tremor might ruin the sharpness of a photograph. The body is of the

large 2-inch diameter, with a drawtube giving a variation in length from 140 mm. to 200 mm. A rack and pinion double extension drawtube, as illustrated on page 103, can be fitted if desired. An interchangeable binocular body can be fitted to the instrument, and a circular rotating stage can be made in place of the square stage; but in this case a gap cannot be cut out in front, and some of the advantages of the interchangeable substage apparatus are lost. The apparatus can be interchanged, but only after racking down the substage by the amount of the thickness of the stage.

With this massively made microscope, the body and apparatus can be relied upon to be always truly in the optic axis, the manipulation of one part of the instrument does not tend to upset the adjustment of the other parts, and when using the very highest power lenses it is a pleasure to work on account of its stability and the delicacy of all its adjustments.

The Binocular Microscope

Hitherto binocular microscopes have not been used for research work, except in special cases. For practical purposes the monocular has for many years held the field, and the use of binoculars has practically been restricted to workers who only use low powers, or for exhibition purposes. The reason of this is simply explained: the one advantage of using two eyes did not outweigh the loss of the many advantages possessed only by the monocular stands.

Binocular microscopes may be divided into three types, and a brief description of each type will set forth their respective merits and demerits.

Fig. 99.

Type 1, best represented by the "Wenham," bisected the beam of light that emerged from the object glass (O, Fig. 99) and directed the right-hand half into the one eye, the left-hand half into the other.

Binocular vision with this was not equal to monocular, because by reducing the size of the beam of light which formed each image it reduced the resolving power of the microscope. It could not be used with high-power object glasses, because the prism could not be placed sufficiently close to the back lens of the object glass to properly bisect the beam of light into two separate halves before the rays had intermingled. Efforts to accomplish this by mounting high-power object glasses in special short mounts only partly overcame the difficulty, and rendered the use of revolving nosepieces impossible.

This type of instrument involved long tubes and consequently bulky instruments, and could only be satisfactorily

employed when the illumination was specially arranged so that the whole of the object glass was equally illuminated. If, for instance, a fine oblique feather of light was employed, it would only enter one side of the object glass and consequently only one eye would receive the light, the other eye seeing no image. In like manner, if more light happened to be entering one half of the object glass than the other, the illumination of the two eyes was different, often to the extent of making binocular vision inoperative.

It will be seen that none of these disadvantages exists in the new instrument here described.

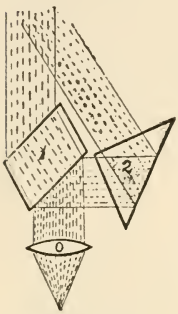


Fig. 100.

The second type of binocular was in one respect on the right principle. In all models of this type the beam of light is not bisected into two halves, but the entire beam is filtered into two portions, so that some light from every part of the object glass goes to each eye.

The Powell and Lealand (Fig. 100) shows the earliest form, the whole light from the object glass (O) impinges on a glass plate (1) and the major part passes through this thick glass plate, emerging in a direction parallel to and almost continuous with its original direction; but a percentage is reflected at the first surface and proceeds to the prism (2), which reflects it up a second tube, placed at an angle with the optic axis of the direct beam.

This type of instrument gives equal resolution to that of a monocular microscope because the size of the beam which forms each image is not reduced.

With the Powell and Lealand form, however, the tubes of the microscope must be long and the instrument bulky, and it suffers from the very grave defect that the light that is reflected is so feeble as to be insufficient for satisfactory vision. The light in one eye is only of about one-sixth the intensity of that of the other.

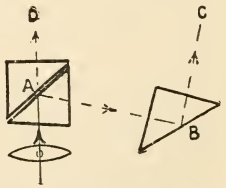


Fig. 101.

The Abbe binocular eyepiece, which acted optically on the same principle in not bisecting the beam into two halves, but in filtering the light by a reflected and a refracted beam, improved the light distribution, but only made the relative illumination in the two eyes about 1 to $2\frac{1}{2}$, and, while not curing this defect, introduced a further disadvantage. The general plan of this eyepiece is shown in Fig. 101, and it will be seen that the light which is split up into two by reflection and transmission at the surface is resolved into two beams, one (A D) which is transmitted, the other (A B C) which

is reflected, and the reflected light at the time it emerges has travelled a path that is longer than the direct light by the amount A B. This difficulty was overcome by making a special pair of eyepieces whose focal points were different in position, but it limits the use of the instrument to the use of special eyepieces.

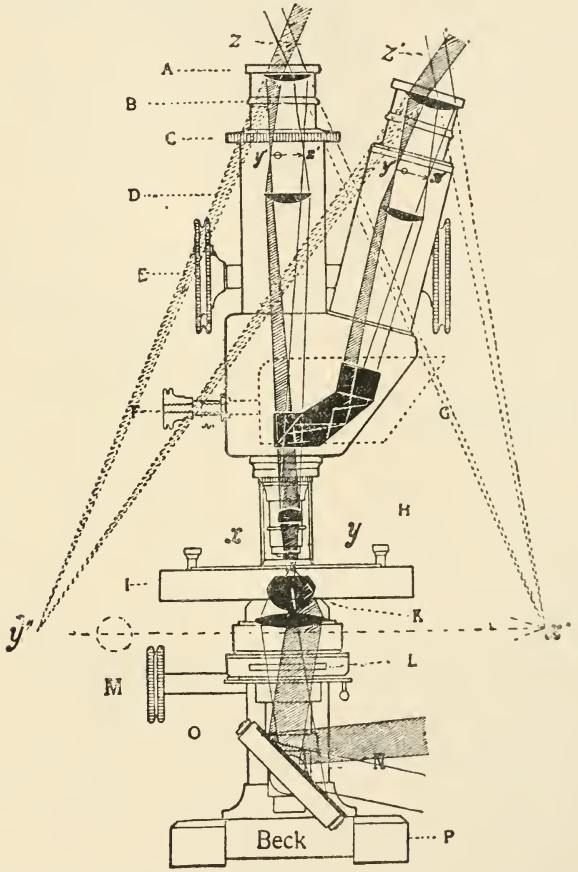


FIG. 102.—Diagram showing paths of light through the Beck Binocular Microscope.

(A) Eyepiece.
(B) Drawtube.
(D) Body.
(E) Coarse focussing adjustment.
(F) Prism box knob.
(G) Sliding prism box.
(H) Object glass.
(I) Stage.
(K) Substage condenser.
(L) Iris diaphragm.
(M) Substage focussing adjustment.
(N) Mirror.
(O) Pillar.
(P) Base.
($x\ y$) Object.
($x'\ y'$) Image formed by object glass.
($x''\ y''$) Virtual image formed by eyepiece.
($z\ z'$) Ramsden discs—conjugate images of back equivalent plane of object glass.

The second type of instrument therefore, while giving good resolution, was not free from other defects, and was not therefore equal to the monocular.

The third type of binocular, which consists of two microscopes set at an angle to one another, both pointing at the focal point, while quite satisfactory in its performance, is limited to the use of low powers and requires specially mounted and accurately adjusted pairs of object glasses.

It will be gathered from this description of the properties of previous instruments what were the difficulties that had to be overcome in making a really satisfactory binocular, and in the following description of the properties of the Beck binocular we treat each point separately, explaining how the objections have been removed.

Resolution.

The resolving power of a microscope is a measure of the fineness of detail that it will depict in the image which it forms, quite apart from the magnifying power. The microscope must have sufficient magnifying power to render such detail visible to the eye, but no amount of extra magnifying power is of use unless the resolving power is sufficient to produce an image containing the requisite detail. Resolving power depends upon the size of the cone of light which forms each point of the image. Suppose the lens O (Fig. 103) represents the object glass forming an image of the central point of the object C at a point D in the centre of the image; the resolution for a given magnifying power will depend on the diameter A B of the cone of light A D B which forms the image; this cone of light has an exact ratio to the angle A C B of the light which enters the lens from each point of the object, and it is by means of the angle A C B that the resolving power is generally and more conveniently expressed as numerical aperture (N.A), but it might be expressed with reference to the angle A D B. It is evident that if the cone of light A D B be bisected and the complete half O D A be used to form the image received by one eye and the complete half O D B used to form the image received by the other eye, the cone of light forming each image is only half the size, and the resolution or power of depicting fine detail is reduced thereby; thus this method of making a binocular microscope reduces its power of resolving fine detail.

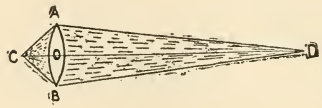


Fig. 103.

The new Beck binocular acts on a different principle. Above the object glass is a prism shaped as shown in Fig. 104. The whole of the light from the object glass O passes through the surface of the glass B A to a surface E A, which is coated with a semi-transparent surface of silver. This allows part of the light to

pass through and part to be reflected into the second tube of the microscope as shown by the dotted lines, thus the full size beam goes to form each image and no lack of resolution occurs; two perfect pictures are produced with maximum detail, one in each eye.

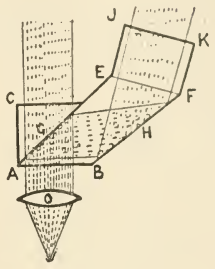


Fig. 104.

It may be expected by those who have not followed the vast improvement that has recently taken place in optical manufacture that the effect of light passing through the prisms would injure the quality of the image. This is not the case; the flat surfaces can be polished without an error of one-millionth of an inch, and no optical designer now hesitates to make use of prisms in optical instruments even of the most exacting requirements.

Equal illumination.

As the transparency and reflecting power of the surface E A (Fig. 104) can be regulated according to the amount of silver that is deposited, the relative intensity of each image can be made identical, and the right- and left-hand images are equal in brilliancy. As to the intensity of the mental impression, it has been urged that when an initial body of light is divided into two brilliant parts and one part is sent into each eye of the observer, the effect of brilliancy is the same as if the whole light be directed into one eye only. Certainly there is some reason for this argument, though it may be an over-statement of the case. It is, however, no disadvantage if a slightly stronger light is required with a binocular than a monocular microscope. The monocular observer, in order to more readily concentrate his attention on the employed eye, is apt to use an illumination that is far too brilliant, to the detriment of his eyesight. In the use of the binocular, both eyes are equally stimulated, and there is no temptation to use excessive illumination, and theory goes to show that a low illumination is more efficient for displaying fine detail.

Equal optical paths for both images.

The diagram of the binocular prism (Fig. 104) shows that the distance from the surface E A, where the beam of light is divided into two portions, to the two eyepieces is not of equal length, the light on the right-hand side has to travel a distance G H farther than the light that passes directly through. It would, therefore, not be possible to focus both beams of light to the same points in the two eyepieces; if this were not compensated, one image would be out of focus when the other was sharp. Fig. 105 shows how placing a plate of glass in the path of a beam of light converging to a focus at A has the effect of extending the focus to B, and

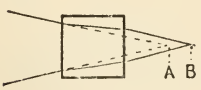


Fig. 105.

is a means of overcoming what would otherwise be a serious error. It is corrected in the Beck binocular by combining a parallel plate of glass of the required thickness with the right-hand prism, thus equality in the focus and in the magnifying power of the two images is ensured. The binocular prism is carried in a sliding box in the body of the microscope (Fig. 102). By sliding it out of the optic axis the microscope is converted into a monocular instrument, or by unscrewing the knob (F, Fig. 102) it can be slid completely out of the microscope for cleaning or dusting. It is quite safe to remove the prism complete in its box, as it returns with accuracy to its exact position, and the adjustment will not be interfered with. Dust may be removed from the prism with a camel's-hair brush or it may be carefully wiped with a silk handkerchief or leather; but glass should never be touched with the fingers, a greasy smear damages the definition more than a considerable amount of dust.

The fact that when the prism moves to one side the instrument becomes absolutely the same as a monocular microscope renders this microscope equally useful for photography, drawing, micrometry, or any other purpose.

Many believe that eventually the binocular will be almost universally used, but we recognise that at present this opinion may not be shared by all, and that an opportunity of using either monocular or binocular should be provided.

Short tube length.

The construction of this binocular renders it possible to retain the short tube of the compact monocular microscope. This binocular body, indeed, can be fitted to most of the various recent models of monocular microscopes. When the drawtubes are partially extended, the tube is of the standard 160 mm. length, the binocular microscope is thus rendered as compact and serviceable as the monocular type. In the older types of binocular microscopes a tube of about 9 to 10 inches in length was required in order to extend the eyepieces to the necessary interocular distance, but examination of the diagram (Fig. 102) shows that, owing to the peculiar construction of the prism, the tubes, instead of converging towards the prism, converge to an apex about 3½ inches below it; thus, although the standard angle of normal convergence is retained, the tubes need not be long to give the required separation for the eyes. The tubes converge at an angle of about 14°. This will be found in practice to give absolute comfort for either long or short periods of working. The eyes are in exactly the condition required for reading a book.

Binocular telescopes which are used with the eyes looking out horizontally at distant objects generally and correctly have their two tubes parallel, but this is unsuitable for a microscope. The microscopist who uses his instrument alternately with examining objects on the table on which it stands would find it difficult

and tiring to constantly change the direction of his convergence, such is the force of habit that the mere action of bending the head downwards induces the convergence of the eyes necessary for examining near objects.

Any make of object glass or eyepiece of the standard size can be used. There are absolutely no special requirements—a revolving nosepiece, an objective changer, or any form of apparatus can be employed. Any make of object glass or eyepiece

The interocular distance is varied by turning the milled head on the direct tube of the microscope (Fig. 108), this causes both drawtubes to move in or out and alters the distance between the oculars from 2 inches to $2\frac{1}{2}$ inches, which, as the observer's eyes cannot be in contact with the eyepieces, represents interocular distances of about $2\frac{1}{4}$ inches to $2\frac{3}{4}$ inches. The tube length is the standard 160 mm. at an intermediate position. For those whose eyes are farther apart than this, tubes can be so constructed that they give extra separation. The interocular distance.

If the two eyes of an observer are dissimilar, the necessary lens to render them equal can be supplied in a cap to fit over the eyepiece. This is a better plan than the separate focussing adjustment provided in a binocular telescope, because to effect an alteration in focus by means of the microscope eyepiece requires such a large amount of motion.

The advantages of binocular vision are not only that a stereoscopic relief can be obtained: the rest to the eyes prevents fatigue and improves the quality of the vision; not only is more seen, but the perceptive faculties are much more constant. It is frequently found that after a quarter of an hour's examination with a monocular microscope, the perception of fine detail goes and does not return till after a pause. This does not seem to occur with binocular vision, or at least to only a slight degree. Binocular vision.

A further and somewhat more serious consequence of monocular vision is that the employed eye generally loses its visual intensity of light. In order to concentrate the attention upon the employed eye, a stronger light than is wise is often used, and by degrees an illumination that appears white to the unemployed eye is only grey to the other. Most microscopists who do not force themselves to use the two eyes alternately will find that the perception of light is less with the eye which has been most used.

Doubt has been at times expressed as to whether a microscope looking at an object with a single object glass can under any circumstances give a really stereoscopic relief. Those who have worked with a binocular microscope do not retain such a doubt, and the explanation of the phenomenon is quite satisfactory. Suppose that O (Fig. 106) represents the objective and that an object at X consists of a fine blade of material placed on end, all the light from the left-hand of this blade which enters the object glass at all Stereoscopic vision.

reaches the left-hand of the lens only, and from the right-hand side of X reaches the right-hand side only. If the light from the lens O is geometrically divided and passed to one eye at A, and the other at B, a perfect stereoscopic picture will result, as though the eyes were looking on both sides of a card held in front of them in the well-known experiment on binocular vision. A microscope inverts the image, and consequently to pass the correct image to the eyes to obtain the stereoscopic relief, the light from the right-hand side of the object glass must be passed to the left eye, and vice versa.

FIG. 106.

The first kind of binocular microscope described (Fig. 99) bisected the beam of light at the back of the object glass and passed one beam to each eye, and for long it was supposed that unless the beam were thus divided immediately behind the back lens of the object glass, no microscope could be made which would give stereoscopic relief. By examining the diagram of the rays passing through a microscope as indicated in Fig. 102, it will be seen that the rays of light intermingle after they leave the object glass, and at no other place between the lenses could the right-hand half of the rays entering the object glass be separated from the left half. It might be done for any particular bundle like that indicated by the shaded portion, but not for all such bundles; a diaphragm placed, for instance, over half the field half-way up the tube would obliterate almost all the light from one side of the object, and allow all to pass from the other side of the object. It would not obliterate all the rays that enter from one side of the object glass, but would obscure half the object.

It will, however, be noticed in Fig. 102 that all the rays of light, after passing through the microscope, pass through a small area called the Ramsden circle ($z\,z'$) just above the eyepiece. This circular disc is a picture formed by the eyepiece of the aperture of the object glass. At this place the light may be divided just as if it were the back of the object glass, and if in this place a complete circular bundle of light is received from each eyepiece of a binocular microscope it is possible, by placing suitable diaphragms at these points, to exclude from the right eye all light that enters the object glass from the right-hand side of each point on the object, and from the left-hand eye all light that enters the object glass from the left-hand side of the object points. Thus, two D-shaped diaphragms placed at the positions of the Ramsden circles exclude from each eye the correct portions of light and give the stereoscope relief with the same efficiency as the first kind of binocular microscope, except for the loss of light. There is, however, a practical objection to this procedure. The proper use of the microscope is dependent on the eyes being so placed that these discs are within the eye very near to the pupils,

and therefore such suggested diaphragms cannot be placed in the correct positions—in fact, due to the eyelids and eyelashes of the observer, they cannot even be placed near the correct position.

But there is another method of stopping out the portions required to give a stereoscopic picture. If the eyepieces be placed at a slightly incorrect interocular distance, the pupils of the observer's eyes cut off the edges of the two Ramsden discs (Fig. 107), and as the stereoscopic effect with a high-power object glass is generally exaggerated, a very small movement is sufficient to give perfect depth of vision.

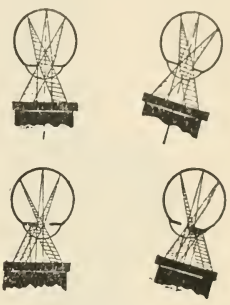


Fig. 107.

The tubes of the new microscope are, however, inclined, and there is no necessity to vary the interocular distance. The observer naturally places his eyes so that the whole of the Ramsden discs (Fig. 107) enter the pupils of the eyes, and obtains all the advantages as to aperture, resolution, and illumination of a monocular microscope. Then, by moving his head either forward or backward, he cuts off with his pupils the one or other side of the Ramsden discs and obtains either stereoscopic or pseudoscopic relief instantly. The movement required is scarcely over an eighth of an inch, and the result is that all the advantages of stereoscopic relief are obtained without sacrificing anything.

The result of the movement of the head is very astonishing: if objects are being examined which lie on different levels, one point appears either in front of or behind another at will, and the position of the observer's head indicates which is the stereoscopic or pseudoscopic picture.

The Beck high-power binocular body can be supplied on any of the microscopes illustrated, either in place of the ordinary body or as an extra interchangeable body.

Metallurgical microscopes require certain special features because almost all objects for which they are used require illumination from above. A great deal of their examination is done with high powers with one or other of the vertical illuminators mentioned on page 41. It is, therefore, important that the beam of light for the use of these illuminators, having once been adjusted, should be allowed to remain in a fixed position. If the body tube of the microscope to which these illuminators are attached is focussed up and down to examine specimens of different thickness or to enable different object glasses to be used, the illuminator cannot be kept opposite to the illuminating beam of light. Metallurgical microscopes must, therefore, be made in a manner that will overcome this difficulty. The three following forms of microscopes show three methods of accomplishing this.

Metallurgical microscopes.

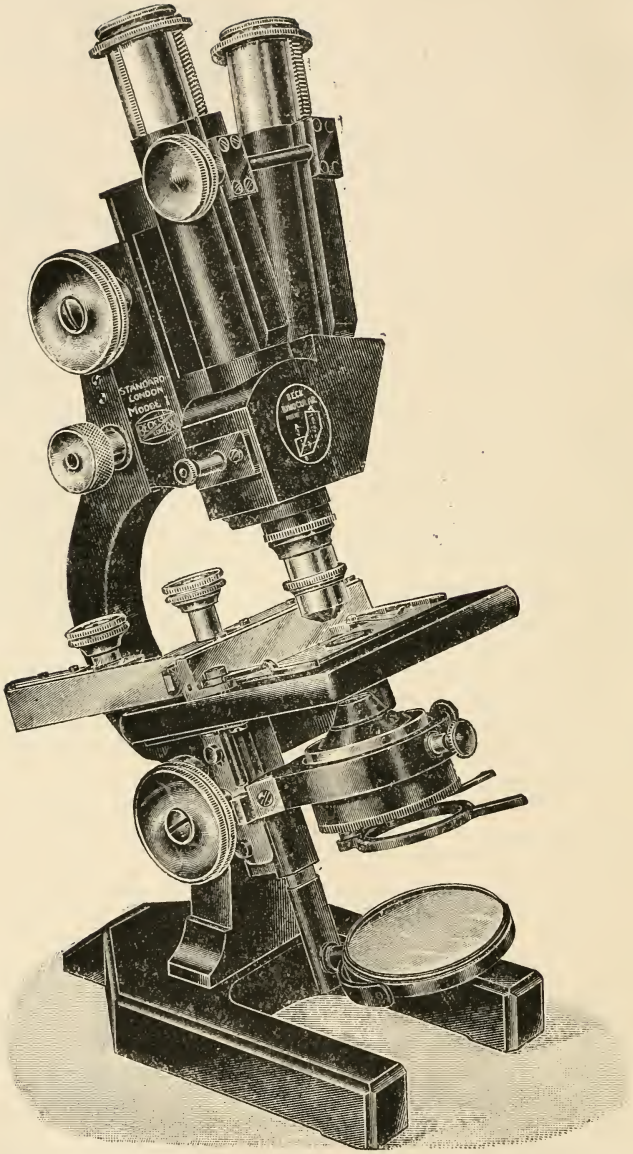


Fig. 108.—The Binocular High- and Low-power Microscope as applied to Stand No. 3213.

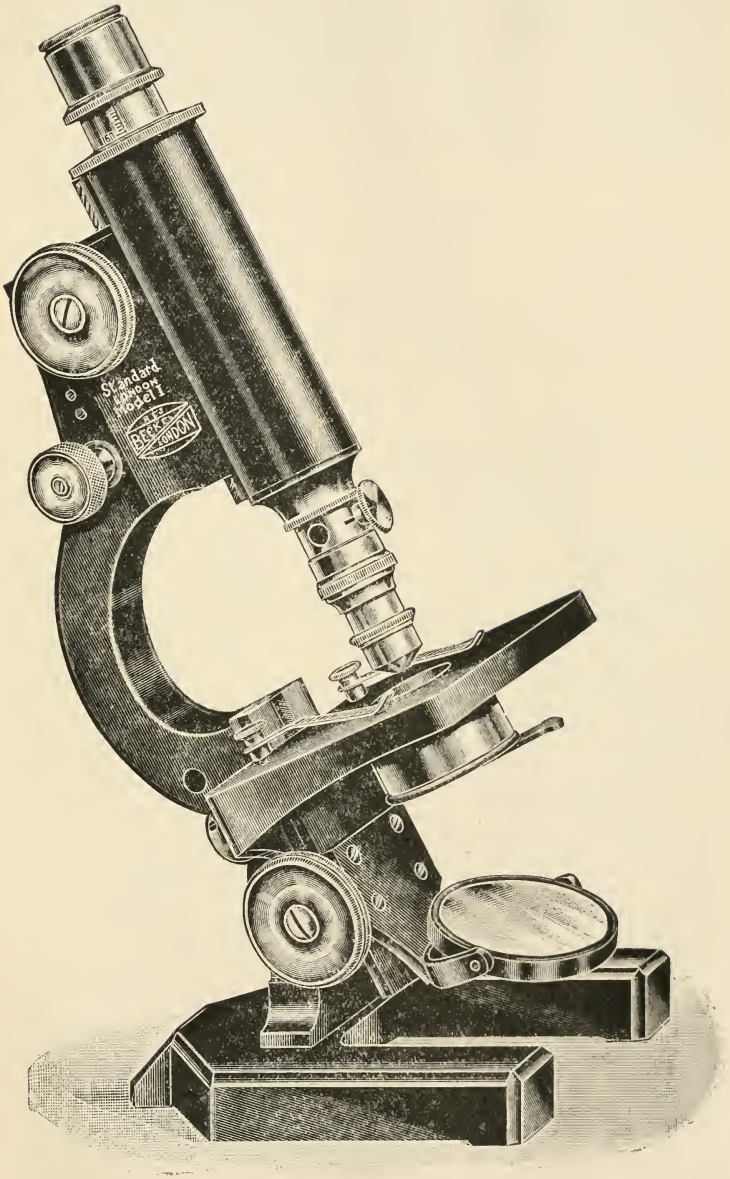
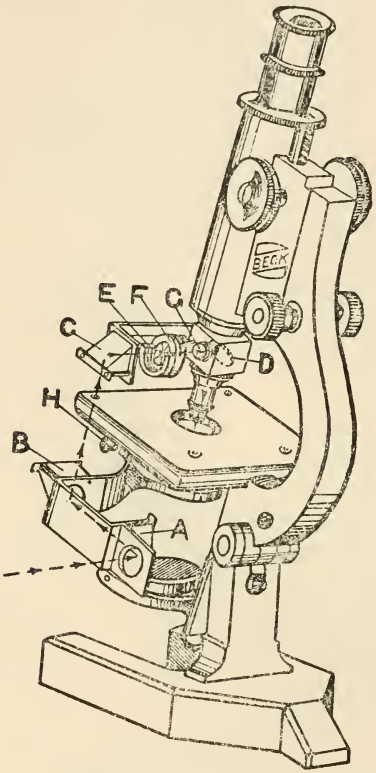


Fig. 109.—No. 3227, Metallurgical Microscope, with rack and pinion focussing stage, object glass, and vertical illuminator.

The Beck-Rowley Metallurgical Attachment (Fig. 110)converts the Standard London Microscope into a metallurgical instrument by the use of prisms. The Standard Metallurgical Microscope (Fig. 109) is a model of the Standard London Microscope in which the stage of the microscope is not fixed to the limb of the instrument, but is carried in a strong slide, and can be focussed up and down by means of a rack and pinion, so that the focussing can be done by the stage and not by the body. It does not detract from the performance of the instrument for other purposes, and when racked up to the correct position will work with the mechanical stage of the standard microscope. It can also be supplied with any of the standard substages, although for purely metallurgical purposes a substage is not required.



The Beck-Rowley Metallurgical Attachment. FIG. 110.—No. 3225, Standard London Microscope, and Metallurgical Attachment.

The third method (Fig. 111) has an electric light fixed to the body tube of the microscope which moves up and down with the illuminator as it is focussed.

The Beck-Rowley Metallurgical Attachment converts an ordinary microscope into an efficient metallurgical instrument The attachment may be readily attached or removed without any alteration to the microscope.

With this illuminator the light is projected along the tilting axis of the microscope, and from thence by means of prisms into the vertical illuminator; when this method is employed the microscope tube can be racked up and down for focussing in the ordinary way, and the inclination of the microscope can be effected without in any way interfering with the original accuracy of illumination.

It will be seen from the illustration that the attachment consists of two pieces, one screwing on to the body-tube of the microscope, and including the vertical illuminator (D), and the other fitting into the standard substage or understage and held in place by the screw H.

Light from any desired source is projected into the prism A and reflected into the prism B, and from thence to the prism C and again into the vertical illuminator, where the light is reflected, by the thin glass reflector D, downwards through the object glass to the metal surface to be examined.

A removable lens is fitted at G which can focus the iris diaphragm (F) upon the object and enables all extraneous light to be cut off; a holder (E) for light filters and ground glass is placed immediately behind the iris diaphragm and enables the diaphragm to be used as the light source. The iris diaphragm and ground glass can be moved so that it can be focussed upon the object, thus giving so-called " critical " illumination.

The reflector in the vertical illuminator is readily removed for cleaning or replacement. A thin glass and a thicker parallel glass, a green glass and a ground glass are supplied with each instrument.

For geology and mineralogy the illuminator will also be found of value in the examination of polished specimens of ores and rocks. The fact that objectives of different powers can be used and focussed without interfering with the adjustment of the light is of special importance in the examination of opaque metalliferous minerals.

The bench metallurgical microscope (Fig. 111) has no pillar and base. It has a limb carrying the body with the usual coarse and fine adjustments fixed to a large square stage. This stage is carried on four levelling screws one at each corner of the stage. The microscope can be stood upon a table or bench and used in the ordinary way with specimens placed on the stage, or it may be placed on a large metal or other surface, and the surface examined by focussing the object glass down through the aperture in the stage. To render this microscope convenient for metallurgical work a metal filament electric lamp is attached to the illuminator and is provided with a pair of light-tight tubular covers. It moves up and down as the microscope is focussed, thus allowing the instrument to be focussed without interfering with the illumination. The prism illuminator is supplied with this microscope because it is more suitable for low powers and almost equally good for high powers. This instrument is useful for many other purposes, including the Brinnel test, in which case a scale is fitted into the eyepiece. The electric filament lamp can be used on any voltage from 100 to 250 volts, and on direct or alternating currents. It is troublesome to use a lamp of low voltage which requires accumulators, but for those who have 6- or 12-volt accumulators suitable lamps can be supplied.

The bench metallurgical microscope.

In the tubular portion connecting the lamp to the illuminator there are two slots into which colour screens, ground glass, or a focussing lens can be dropped, and a ground glass, a green glass, and a lens are supplied with the microscope for the purpose.

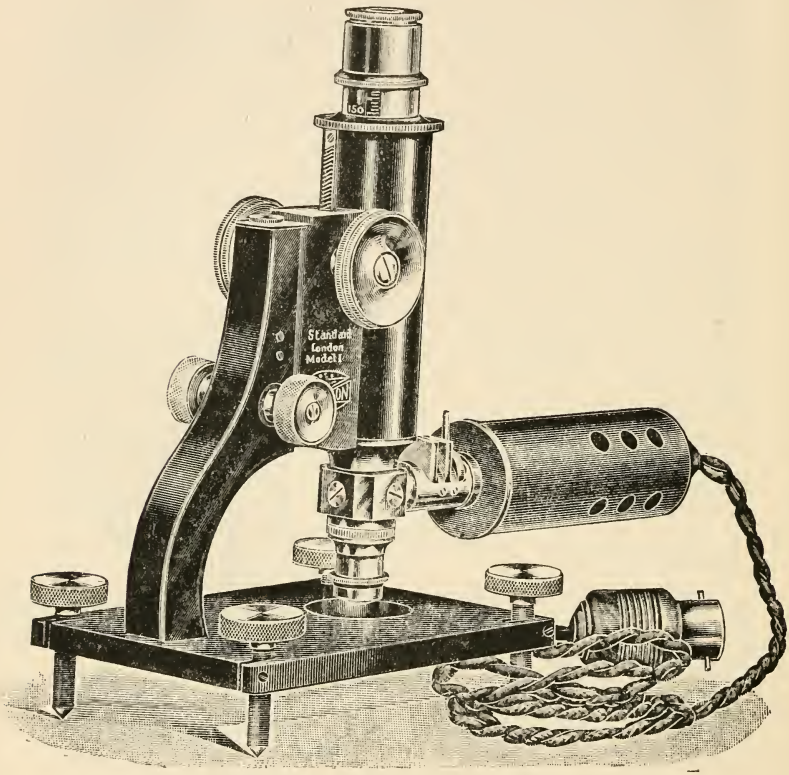


Fig. 111.—No. 3226, Metallurgical Bench Microscope with prism illuminator and electric lamp and fittings.

Petrological microscopes.

A petrological microscope is essentially an ordinary microscope provided with a number of special adjustments and appliances for the study of rocks and crystals. The most important of these additions are a polarising apparatus and a rotating stage. A polarising apparatus consists of a Nicol prism made of Iceland spar which must be placed below the object to be examined and a similar but somewhat smaller prism which must be placed above the object. At least one of the prisms and the object must be capable of rotation, and the amount of the rotation determined on a scale. There must be a means of rapidly throwing

out of the axis one, or preferably both prisms, so that an immediate change from polarised to ordinary light may be made.

The eyepiece must be provided with cross lines for measuring the angles of crystals by setting first one and then the other edge against one of the lines and measuring the angle of rotation of the stage required to effect such setting. As the various object glasses and their mountings are never perfectly interchangeable, a rotating stage must be provided with centring adjustments, so that the axis of rotation can be made to exactly coincide with the optic axis. The Sloan object glass changer described on page 20 is a very useful appliance for adjusting individual object glasses, and is far preferable to a double or triple nosepiece for rapidly changing them. The prisms should be provided with spring clips so that as they are rotated the positions when the prisms are " crossed " may be felt. The lower prism, called the polarising prism, should be large enough to enable the back of the condenser or the object to be fully illuminated, but its size is determined to some extent on the supply of Iceland spar, which cannot always be obtained in large crystals. The upper prism, called the analysing prism, need not be so large, and may be fitted in one of three positions—either immediately over the object glass, in the interior between the two lenses of the eyepiece, or over the top of the eyepiece. If it is immediately over the object glass it makes a slight change in the exact focus of the microscope when pushed in and out unless furnished with a compensating lens or block of glass, which is seldom fitted, as most observers object to the introduction of an extra optical element, when there is no real necessity. With the analyser in this position the use of a quartz wedge is less convenient than in the other two forms. In both the other forms the quartz wedge fits through a slot which is in the focus of the upper lens of the eyepiece. The analysing prism in the interior of the eyepiece is probably the most convenient form, because if fitted above the eyepiece its considerable thickness prevents the eye from being placed in the eyepoint of the microscope (see Fig. 1, page 9) and seriously restricts the field of view.

The interference rings and brushes of crystals are formed if a wide-angle cone of light be made to pass through the object by a small, specially made substage condenser and if this wide-angle cone of light be collected by a wide-angle object glass. A 1/6-inch (4-mm.) is generally used for this purpose. The image of these rings and brushes is formed at the back focus of the object glass very close to the back lens of the latter, and there are three methods of observing them. In the microscope in which the analysing prism is immediately over the object glass, the eyepiece may be taken out and the eye placed two or three inches away from the upper end of the tube of the microscope. The image will then be seen, but it will be very small. If the analysing

prism is not in this position this method is not permissible, because removing the eyepiece removes the analysing prism, which is an essential to the image being formed. When an eyepiece analysing prism is used, a lens known as a Bertrand lens may be screwed into the lower end of the drawtube or placed into the body through a special slot made for the purpose, and the drawtube pushed up and down until the image is clearly focussed. The Bertrand lens converts the drawtube into a low-power microscope which is focussed to give a sharp image of the back focal plane of the object glass, and a magnified image is obtained. This method suffers from the inconvenience that the drawtube must generally be removed to put in the Bertrand lens, and that it is troublesome to use a sliding drawtube in a petrological microscope, as it may interfere with the accuracy of the crossed position of the prisms.

The best method of observing the rings and brushes is by means of a small microscope called a Becke lens, which fits on to the top of the eyepiece and gives a highly magnified image of the eyepoint or Ramsden circle of the microscope (Fig. 1, page 9). The image of the rings and brushes is, as previously mentioned, in the back focal plane of the object glass, but this is reproduced by the eyepiece in the eyepoint, and it may be examined equally well in this position. The use of the Becke lens does not interfere with any of the adjustments of the instrument, and is to be preferred to any other plan.

Petrological microscopes cannot be thoroughly explained without considerable discussion of the theory of polarised light, which is not attempted in this book. There are excellent books on Petrology to which the student is referred, and to whom the following technical description of a petrological microscope will then appeal.

Standard petrological microscope.

The Standard London Petrological Microscope is made in two forms (Nos. 3222 and 3223). Both forms have the rack and pinion spiral coarse adjustment and the double-speed fine adjustment of the Standard London Microscopes; both have a circular rotating stage divided in degrees and cross-finder divisions on the surface with centring screws to set the axis of rotation in the optic axis; they both have cross-wires to the eyepieces, a polariser in a swing-out fitting below the stage, and a wide-angle series of converging lenses in a sliding fitting in the stage. This condenser can also be fitted in an independent swing-out and focussing arm, which enables the condenser to be thrown out of the optic axis in a manner similar to the polariser. The polariser is provided with spring clicks at positions of crossed prisms and lines at parallel positions. No. 3222 has an analyser in a push-out fitting above the object glass at the lower end of the body. Below this is a slot covered by a revolving tube when not in use, for the insertion of mica or quartz plates. A Becke lens slides over the eyepiece for examining the rings and brushes of crystals.

No. 3223.

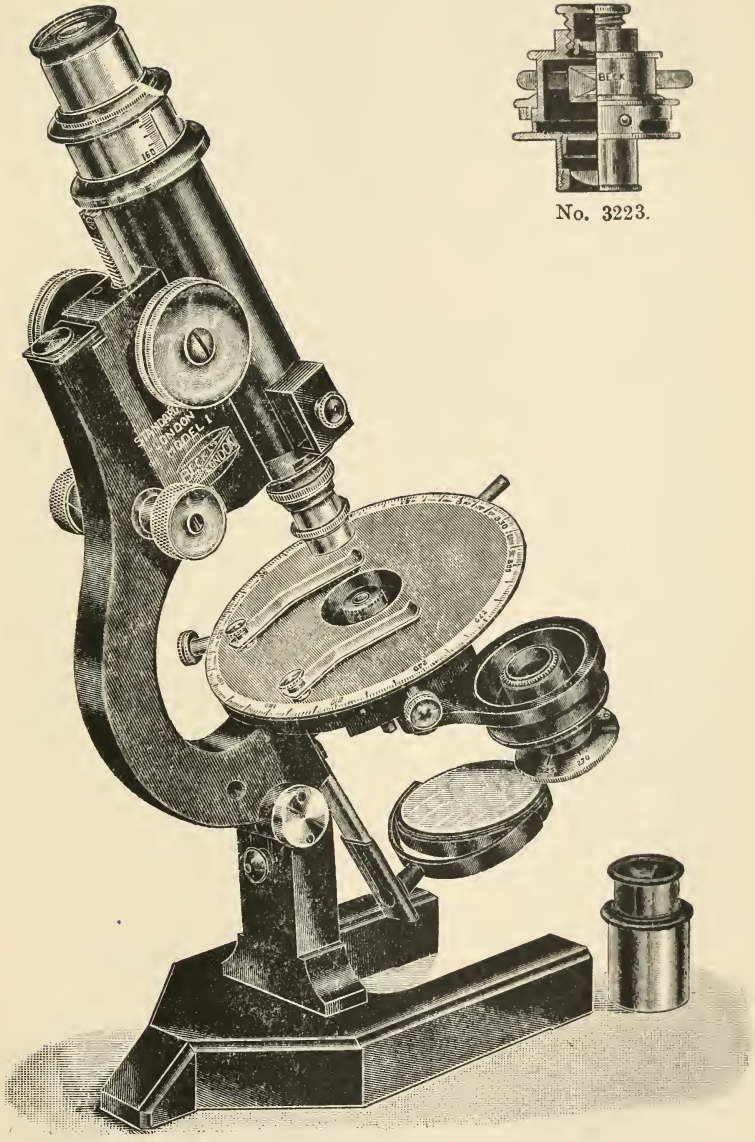


Fig. 112.

No. 3222, Petrological Microscope Nosepiece Analyser.
No. 3223, Petrological Microscope Eyepiece Analyser.

No. 3223 has the analysing prism in a revolving fitting within the eyepiece. It is a form of the Abbe prism, devised by Mr. E. M. Nelson, which pushes in and out of position. Its great advantage is that it gives the full field of view. Its only disadvantage is that in certain circumstances a faint second image of the cross-lines can be observed, but this is of no practical disadvantage. It is provided with spring clicks at positions of crossed Nicols and lines at parallel positions. Below the analysing prism a slot is provided for the insertion of a quartz wedge or mica plate. The top lens of the eyepiece is provided with an adjustment for focussing to either the quartz wedge or the cross-wires, and a Becke lens is provided, fitting over the eyepiece, for examining the rings and brushes of crystals.

The whole eyepiece pushes into the drawtube with a pin fitting into a slot so that the position of crossed Nicols may be correct when the prisms are set in their clicked position. On either side of the clicked position a line is marked on the flange of the eyepiece which is $2\frac{1}{2}°$ away from the true position for the total extinction. By setting the analyser to these positions a better determination of the extinction can sometimes be obtained. A shutter with a series of apertures is provided which can be introduced into the field of view to cut off all parts of the field except the centre. A slot is provided at the lower end of the polariser fitting for the insertion of a plate with a fine aperture and a slit, for the testing of refractive index by the Becke shadow test.

Circular mechanical stage.

A circular mechanical stage (page 52) can be fitted to either of the above instruments, and all apparatus of standard microscopes can be supplied, but the substage apparatus is supplied in slightly longer mounts to accommodate for the extra thickness of the mechanical stage.

CHAPTER VII

THE MICROSCOPE AS A RECREATION

Science owes more to the discoveries made with the microscope than to those made with any other instrument, but it is not always appreciated what a fund of enjoyment is available to all by making use of the addition to one's eyesight that the microscope affords. The reader may have met an enthusiast who devotes hours at a time to gazing down the tube of this instrument, and have wondered what could so engross his attention. If questioned, such an enthusiast might have explained that in the stagnant ponds and ditches he had discovered numbers of curious and amazing animals—creatures that had been unobserved for thousands of years because they were small—creatures more varied than the inmates of the Zoological Gardens, and of types of astonishing originality and beauty.

A visit to a weedy pond with a few bottles, the collection of some of the water, weed, and mud, and their examination under the microscope will be convincing proof that the enthusiast was correct.

For some time an observer may be content to watch these new-found animalcula and wonder at their curious diversity of appearance, but the time will probably arrive when he will desire to know more of their habits; he will then discover that during the last sixty or seventy years books have been written about them. The first glance at such books may fill him with dismay; they are filled with long words and terrible names, and it would almost appear that a new language has been evolved to describe these minute creatures.

Further examination, however, will show that the terminology is but a thin veneer and that a method is discernible in the apparent madness of these writers. They state that they have discovered a history of existence, which they call development, which shows how in the ages that have gone, great and complex animals—perhaps man himself—have grown from simple and minute beginnings. The more enterprising of these simple forms have, they say, from time to time, altered their characteristics and grown through gradual stages to more complex forms. Some have advanced while others have remained in their original con-

dition. These steps have not been obliterated, and amongst the denizens of our ponds and ditches are to be found specimens of many of these early phases of life—specimens so nearly alike that it is quite possible to follow the lines along which one form has developed into another. Such a conception leads one to examine the ponds and ditches with a connected idea.

Fig. 113.—Amœba.

The class of creatures which represents this least complex form of existence is called Protozoa, quite as simple a name as kangaroo when you become accustomed to it, and to those who remember their classics a much more descriptive one.

In almost any pond with weed, a careful search will produce a creature called an Amœba, which is the least elaborate piece of living animal matter known. One calls it a piece of living matter, for it is nothing more than a morsel of jelly, which changes its shape every minute. This jelly has no case or skin, but, as it does not dissolve, it remains separate from the water like a bubble of oil. It can move its contents to one end of itself, thus increasing for the time being that end and diminishing the other, and so it flows about in any direction, altering its shape to an indefinite extent, forming itself either into a long projection as a tiny trickling stream, swelling out into circular knobs, or doing both at the same time. In this way it slowly moves about without, so far as can be seen, any fixed intention; and, as the jelly of which it is made is filled with fine particles, the flowing of the fluid creature can be easily watched. Besides these tiny particles there are much larger things rolling about within its substance. These are often recognisable as shells of diatoms and of other tiny creatures that are to be met with alive swimming about in the neighbourhood of the Amœba. If the Amœba be carefully watched, it will be seen that when it comes across something which appears suitable it begins to pour itself out in three or four streams all around the desired object, and these streams, as they meet round the victim, join together. The object thus caught and enclosed remains in the jelly, where it is slowly dissolved.

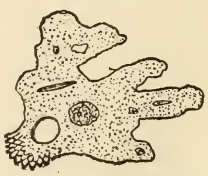


Fig. 114.—Villous Amœba.

The Amœba feeds by literally putting itself outside its food. When the victim has been dissolved, the hard and insoluble parts are allowed to escape back into the water, and the portion that is assimilated goes to increase the size of the jelly. It is not, however, correct to say that this creature consists of nothing but the granular jelly filled with the remains of the things it has absorbed. It has two primitive organs—one, a small spot of

somewhat darker and harder material, is always present and is essential to life. What part it plays is unknown; it appears to be a kind of vital spark, and is called the Nucleus. The other organ is nothing more or less than a good-sized bubble, called the Vacuole.

The Amœba, the simplest form of animal that exists, is so colourless and so transparent that everything going on in its interior is visible. Its structure can be understood at a glance, and starting from this simple form we can find creatures varying from each other but slightly, which show step by step an almost complete series of stages of development up to elaborate organisms.

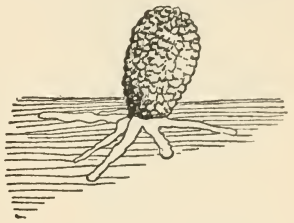


Fig. 115.—Difflugia.

For instance, there is one species of Amœba which has one end of its body hardened into an unchanging shape—just one corner only around which some of the jelly has hardened up at the edge, showing the commencement of the development of a covering, while the rest of the creature is exactly like its simpler brother, having, with the exception of this little corner, no fixed shape, but pouring about as before.

The next shape is reached in the Difflugia. It is an Amœba and possesses the same curious means of engulfing food; but when in the course of its meals it gets outside pieces of sand or similar indigestible material, it retains them, fixing them around the surface of its body until a cap is formed and only a small portion of the jelly is left free. These particles are cemented together with some of the hardened jelly, and form a rough shell in the shape of an egg with one end broken off. From this open end the creature flows in irregular projections of jelly to catch food, and crawls about carrying the shell on its back. It seems to have a power of selection as to the size and shape of the grains that will form a satisfactory shell, and, although there is not a perfect regularity in its construction, it is evidently not left entirely to chance.

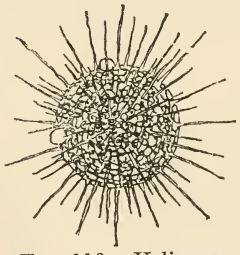


Fig. 116.—Heliozoa.

A further development in the direction of producing a protective covering is shown in the beautiful Heliozoa. In this case a spherical shell is deposited, perforated with tiny holes, through which fine rays of jelly exude in the form of delicate filaments. Here the shell is not built up of pieces of sand, but is probably formed of the products of digestion.

The Foraminifera are from a structural point of view similar to the Heliozoa, being morsels of jelly having the power of forming round themselves shells of chalk extracted from their food and the water in which they live. These shells take myriads of different forms, but have one thing in common: they are perforated with multitudinous holes through which slender threads of jelly exude. To this family belong the shells which form chalk. Innumerable numbers of these tiny creatures fall, as they die, to the bottom of the ocean, forming there, in the course of ages, a layer of chalk which may later be raised by volcanic action above the sea-level.

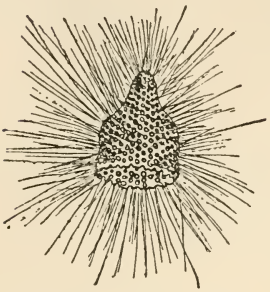


Fig. 117.—Foraminifera.

Such examples illustrate the gradual development of a shell, the creature in every other respect retaining its original simplicity.

We can now trace development in a different direction leading to more complex creatures endowed with locomotion. The jelly or protoplasm of which the living animal is formed appears to slightly harden all round its borders, and a creature of a more or less definite shape is produced, still very elastic and capable of retracting or extending itself to perhaps three times its normal length.

Fig. 118.—Trypanosome.

It has a somewhat pointed end, and the margin of its body is still sufficiently soft to enable it to feed by absorbing into its substance through any portion of the surface small particles of food, but it cannot get outside such large things as the Amœba. This is the creature which, if it finds its way into the blood of animals or men, causes in one case the tzetze-fly disease and in the other the dread sleeping-sickness, and it is known as the Trypanosome.

Fig. 119.—Flagellata.

A further stage shows the development of a flagellum, or whip, which is formed by the drying up and hardening of the pointed end of the body. The flagellum vibrates, and by its aid the creature can swim about with considerable rapidity. Innumerable forms of these Flagellata are found in all decaying matter, and their activity is surprising. Some of them have further extended their cell wall into a sucker, by which they attach themselves to some fixed object, and whole

colonies of such Monads, as they are called, are to be found on weeds, ceaselessly lashing the water with their flagella, causing a current which brings particles of food within their reach.

FIG. 120.—Monad.

FIG. 121.—Collared Monad.

FIG. 122.—Collared Monad in Shells.

A further elaboration of this cell wall is found in the Collared Monads, which are possessed of a transparent cup made from an extension of the hardened margin of their body. In the centre of this the flagellum vibrates, bringing a steady flow of water into this cup or collar. This is the simplest form, but in a more complicated one these Collared Monads have provided themselves with transparent shells of most elegant forms, to the bottom of which they anchor themselves. They retreat right into them for protection from danger, but are found extended when engaged in finding their food.

Thus a series of creatures are met with which possess a shell of the same simple type, consisting of nothing but a piece of jelly with a nucleus and a bubble, but showing great diversity of form as regards the structure of the wall of the cell in which the jelly is contained.

FIG. 123.—Ciliata.

The development of a single Flagellum has been traced, but now we come to the Ciliata, which have rows of hairs. If we imagine the soft, jelly-like exudations of the Heliozoa to be hardened and given a vibratile motion, we have the simplest form of Ciliate, just a tiny ball with rapidly vibrating hairs all over it, these giving it a continuously rolling movement. Myriads of such creatures in different forms exist, some brilliantly coloured, some perfectly transparent.

FIG. 124.—Vorticellæ.

The Vorticellæ are a particularly lovely family resembling groups of dainty lilies. They have a circle of vibrating hairs around the mouth of a bell-shaped body, and are anchored down by a long stalk. If there is a sudden shock and they are alarmed, the stems shut down like corkscrews, and down they go in a flash, taking refuge till the danger is over, and coming out slowly and carefully a few moments later.

Fig. 125.—Stentor.

A somewhat similar species, the Stentor, has a horn-shaped body, with a powerful ring of hairs around its upper surface. It is a most voracious animal and eats almost anything that is brought to it by the strong current of water which its vibrating hairs set up. One species somewhat like the Stentor has a brown shell in which it lives. This is fitted with a trap-door attached to the body of the creature in such a manner that when it retreats into its cell or case the shell closes like the nest of a trap-door spider.

The Protozoa, therefore, display in their living representatives what looks like a fairly complete history of their original development as regards external structure, indicating the creation of a shell or covering, and the creation of cilia and of swimming apparatus. It is now interesting to examine the question of their feeding from the same point of view.

The Amœba simply pours itself round and engulfs any object it meets and wishes to feed upon, the object being then gradually dissolved. Some of its constituents mix with the jelly and are absorbed, and the creature gradually increases in bulk until, being too large for comfort or convenience—if such terms can be applied to such a primitive creature—it splits itself into two parts, each of which is a perfect animal.

Those portions of the food which are insoluble are allowed to escape from the jelly, but there are other portions which, although dissolved, are not suitable or required for nourishment and growth. Water is also taken in with the food particles. It would not do for the Amœba to be constantly filling itself up with useless material, neither would it be satisfactory for it to be continuously diluting itself.

Fig. 126.—Trap-door Animalcule.

Some means must be found to get rid of these waste products, and the means employed are extremely simple. The water and the unnecessary products of the dissolving process form into a bubble, and as soon as such a bubble approaches conveniently near to the surface of the animal, it bursts, discharging its contents into the surrounding water. This is certainly the simplest form of digestion that

can be imagined, but it fulfils all the necessary functions, and, moreover, the constant introduction of water into different parts of the jelly tends to supply the necessary oxygen to keep the animal healthy.

This Contractile Vacuole, as the bubble is named, is the earliest germ of both a digestive and a respiratory system, and we shall now see how from this simple commencement a gradual growth in complexity can be traced.

The bubble of the Amœba forms at any convenient position within its substance, and in some of the Protozoa several of such bubbles form; but the second development is to be found in those allied creatures in which the bubble is always in the same place in the same species, and the water drains from the rest of the body to that spot.

In the next stage the bubble is no longer a perfect sphere, but has one or more extensions, until in the final stage there are minute channels all over the creature which communicate with the main bubble, thus creating a complex drainage system, and this is as far as digestion is developed in the Protozoa.

The development of a mouth presents features of equal interest.

The Amœba has no mouth—it does not eat, it engulfs.

The Difflugia is similar, but its area of action is reduced by the fact that a large portion of its body is enclosed in a shell.

The Heliozoa also have no special feeding organ. When an object becomes entangled in their fine filaments of jelly, it may, if very small, find its way for digestion into the interior of the shell, but as likely as not the fine rays may join up around the object outside the main body, and digestion will proceed there just as well as in the interior.

There is another series of animals called the Acineta, which somewhat resemble the Heliozoa in that they are provided with long, ray-like projections which are hard or leathery except at the tips. Here they swell out into small knobs of soft material, through which small portions of food can be taken in. Such organisms may be considered as having hundreds of mouths.

Fig. 127.—Acineta.

Another series shows a much more direct development. On these the skin is hard except in patches, where alone food can enter; and around these soft patches there is usually a ring of rapidly vibrating hairs, which create a current, bringing the floating particles into contact with the absorbent portion or portions of the body. The Vorticellæ (Fig. 124) have a disc-shaped absorbent surface surrounded by the strong ring of vibrating hairs

The Stentor (Fig. 125), which is larger and a most voracious

creature, has also a large disc-like surface where there is practically no skin to its jelly. The cilia which vibrate around this disc cause a powerful current to flow, and it is amazing to watch the smaller kinds of Protozoa being hustled into the creature's body, where they swim about for a second or two and are then still.

As a final stage we find creatures with only one small opening where food can be absorbed, and the complete development of the mouth is here concluded.

One of the earlier figures shows the dainty little Collared Monad, which consists of a single cell with a vibrating whip, or flagellum, and a very perfect little cup or collar of transparent material. They are often found in large colonies on the surface of weeds. To them we owe our sponges. A microscopic examination of one of the holes of a growing sponge reveals a colony of these little organisms, closely arranged all round the interior of its surface. These have the power of creating instead of shells a fibrous material, which forms the matrix in which they are embedded. In place of shells they deposit hard, flinty spines in the substance of this matrix, and these are called spicules. Thus a sponge consists of myriads of colonies of Collared Monads, their vibrating flagellæ causing a current of water to rush through every cavity of the entire sponge, in order to provide the food and oxygen necessary for the support of the community.

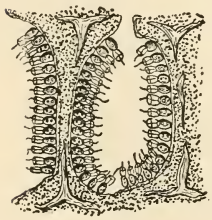


Fig. 128.—Sponge.

The Protozoa show in a series of interesting stages the gradual development of creatures of one cell. Each cell is complete in itself, though, as in the case of the sponge, an approach to a more elaborate form is seen. Nevertheless, here each organ eats for itself, breathes for itself, reproduces itself by splitting in half, and is an individual.

Later stages of development show creatures of more than one cell, in which some cells perform one function and some another, and none are complete by themselves; and the development of the simplest form of life into a more complex animalcule as indicated by a study of the Protozoa is but an indication of the interest that can be obtained by the use of the microscope.

The more elaborate and highly organised creatures met with in water have equal charm and variety. The manner in which they feed upon each other, the manner in which some become parasites, and the methods of reproduction, are all subjects which well repay investigation. The development of many of the animalcula from the egg to the finished and perfect creature has a special fascination, because naturalists have discovered that in this change from stage to stage which certain forms go through

there is a history in an abbreviated form of the stages through which the species originally developed. The so-called water-fleas, for instance, are little crustaceans like small shrimps. They are hatched out from eggs as small oval bodies with short legs, and very little else except one eye. After a time the young creature casts off its skin and becomes rather more elaborate in form. This goes on stage by stage till it develops into a creature with the most complete series of legs, antennæ, tail, and other appendages. It has assumed the appearance of a small shrimp. In some species it goes further, and after having for a short time lived a free and energetic life it develops into nothing but a bag and suckers, which attach themselves to fishes and suck their nutriment from the fish's body.

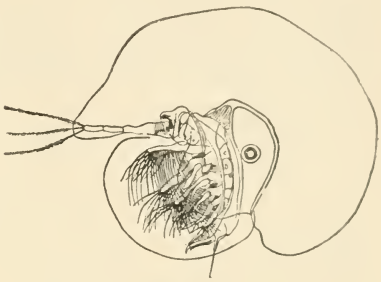


Fig. 129.—Holopedium.

This points to a degeneration in the development which has taken place in the history of a race who found it less fatiguing, if less honourable, to live on other people rather than to fight their own battle in life.

These small Crustacea, generally known as water-fleas, are one of the chief foods of fish, both salt and fresh water. They exist in such enormous numbers in some parts that they even satisfy the appetite of the whale. The sea is sometimes of a blood-red colour due to the myriads of a coloured form of these creatures. There is no pond that has not many varieties, and they can be best captured with a collecting net. Certain forms are phosphorescent, but all are more or less transparent, and can be thoroughly investigated under the microscope. Fig. 129 shows one form found in the lakes of Cumberland, which is supposed to be a delicacy beloved by the salmon trout and the char. This curious species is embedded in an envelope of jelly much larger than itself. It is quite transparent. The rolling of its single eye, the beating of its heart, and the digestion of its food, can all be watched under quite a low-power object glass.

Fig. 130.—Bythotrepes.

Another form with a tail like a long spine and an eye that fills most of its head is shown in Fig. 130.

The study of the development of the cell structure in vegetable life is equally fascinating—how cells which in their simplest forms, having all similar functions, group themselves together into colonies. Some of the constituents take on certain functions only, leaving others to accomplish different work, until a complex vegetable growth is built up of cells, all of which have their own characteristics.

The circulation of the sap in plants can be readily observed. The breathing apparatus of plants where they absorb carbonic acid and liberate oxygen can be found on the under-surface of most leaves. The hairs of plants form a study in themselves. Fig. 131 shows the hair of the stinging nettle: on the left it is in its undamaged condition. It has a knob on the end, and a closed canal can be seen running up the centre. A light touch knocks off the knob, leaving a sharp pointed end which will pierce the skin; and the canal being opened by the removal of the knob, the poison that it contains can enter the prick made by its sharp point.

Fig. 131.—Nettle Hair.

The seeds and pollen of plants are wonderful in the elegance of their design and the variety of their structure.

The spore cases of ferns, with their apparatus like tiny spiral springs for hurling the spores to a distance when ripe, can be found as brown patches on the under-surfaces of the fronds.

Perhaps nothing will create more amusement and interest than the examination of the contents of an open umbrella after it has been held under the bushes, on a hot summer day, while the bushes are lightly beaten with a stick. No one could have imagined what a variety of tiny microscopic insects exist of which most people are entirely unaware. The eyes, legs, wings, proboscis, and other parts of the insects should be examined, and the habits of the voracious little creatures will surprise even the naturalist who is used to the curious manners and customs of the larger animals.

These few notes on the employment of the microscope for the less serious subjects than those from which it is a necessary as a scientific tool, do not do more than indicate a few directions in which enjoyment can be obtained from its use.

PRICE OF INSTRUMENTS AND APPARATUS DESCRIBED IN PREVIOUS PAGES (1922)

MICROSCOPE STANDS

No.	Page		£	s.	d.
3210	97	Standard London Microscope, with plain substage, with iris diaphragm; stand only, in case	10	10	0
3211	93	Standard London Microscope, with spiral screw focussing substage; stand only, in case	11	15	0
3212	100	Standard London Microscope, with rack and pinion substage; stand only, in case	13	10	0
3213	99	Standard London Microscope, with rack and pinion centring focussing substage; stand only, in case	14	10	0
3214	104	Standard London Microscope, with standard body, circular rotating stage, screw focussing substage; stand only, in case	14	5	0
3215	104	Standard London Microscope, with standard body circular rotating stage, rack and pinion focussing and centring substage; stand only, in case	17	0	0
3216	103	Standard London Microscope, with circular rotating stage, large 2-inch body, rack and pinion focussing and centring substage; stand only, in case	19	0	0
3217	103	Standard London Microscope, with circular rotating stage, with double extension rack and pinion drawtubes, rack and pinion focussing and centring substage; stand only, in case	23	0	0
—	116	Binocular body in place in ordinary body on Stands	18	0	0
3221	101	Standard London Portable Microscope, with rack and pinion focussing and centring swing-out substage and mechanical stage, in case	28	0	0
3227	117	Standard London Metallurgical Microscope; stand only	15	10	0
3225	118	Standard Microscope, with Rowley metallurgical attachment; stand only, in case	23	2	0
3226	120	Metallurgical Bench Microscope Stand, without case, but with vertical prism illuminator lamp, with cover tubes and fittings complete for plugging into 220-volt or 100-volt circuit.	13	10	0
3222	123	Standard Petrological Microscope, with nosepiece analyser, eyepiece with cross-wires, polarising and analysing prisms, converging system of lenses, Becke lens, mica ¼-wave plate, and Klein's quartz plate; stand only, in case	29	0	0

No.	Page		£	s.	d.
3223	123	Standard Petrological Microscope, with eye-piece analyser, with cross-wires, polarising prism; stand only, in case	24	7	0
—	122	Independent swing-out and focussing arm, which enables the condenser to be swung out of the axis . . . . . extra	1	5	0
3352	122	Becke lens and converging system of lenses, in fitting in stage-plate with small apertures for Becke shadow test to fit under polariser, and plate with apertures of various sizes for limiting the field to fit into eyepiece slot .	3	15	6
3351	122	Plain quartz wedge, ungraduated . . .	2	15	0
3350	122	Quartz wedge, cemented on gypsum plate (red 1st order), graduated in Retardations . .	4	10	0
3218	116	High-power Binocular Microscope, with square stage and rack and pinion focussing and centring substage; stand only, in case .	32	10	0
	116	Stand as No. 3218, but with detachable mechanical stage	38	10	0
3219	103	High Binocular Microscope, with plain circular rotating stage and centring adjustments; stand only, in case	35	0	0
3219a	103, 52	Microscope as No. 3219, with addition of circular rotating mechanical stage; stand only, in case	47	0	0
—	103, 104	Interchangeable extra monocular large body, with rack and pinion drawtubes extending to 260 mm.	7	0	0
3200a	104	Massive Model Microscope, with plain, square stage and attachable mechanical stage, as on page 99, Abbe condenser, dark-ground illuminator in interchangeable mounts, and one extra substage slide; in case . .	44	10	0
3201a	104	Massive Model Microscope, with mechanical stage as illustrated on page 105, with dry and immersion achromatic condenser and focussing dark ground illuminator and one extra substage slide; in case	70	2	6
—	116	Interchangeable high-power binocular body extra	20	0	0
—	103	Double extension drawtube, with rack and pinion adjustment . . . extra	5	0	0

NOSEPIECE AND OBJECT GLASS CHANGERS

3300	20	Dust-tight double nosepiece	1	7	6
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3280	20	Sloan object glass changer, adapter, spanner, and two fittings	1	7	6
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3282	20	Case to hold three fittings, with object glasses attached in dust-tight spring holders . .	0	11	6

OBJECT GLASSES AND EYEPIECES

3230	77	1½-in. Achromatic object glass (32 mm.). .	2	5	0
3231	77	2/3-in. Achromatic object glass (16 mm.) .	1	10	0
3232	77	1/3-in. Achromatic object glass (8 mm.) . .	4	5	0
3234	77	1/6-in. Achromatic object glass (4 mm.) . .	3	15	0
3236	77	1/8-in. Achromatic object glass (3 mm.), Oil-immersion	6	17	6

No.	Page		£	s.	d.
3235	77	1/12-in. Achromatic object glass (2 mm.), Oil-immersion	8	10	0
3240	77	1½-in. Apochromatic object glass (40 mm.)	4	10	0
3241	77	2/3-in. Apochromatic object glass (16 mm.)	7	15	0
3241a	77	2/3-in. Apochromatic object glass (14 mm.)	7	15	0
3242	77	1/3-in. Apochromatic object glass (8 mm.)	9	10	0
3244	77	1/6-in. Apochromatic object glass (4 mm.)	11	0	0
3245	77	1/6-in. Apochromatic object glass (4 mm.), with correction collar	12	0	0
3248	77	1/12-in. Apochromatic object glass (2 mm.), Oil-immersion	18	0	0
3260	88	42-mm. ×6 Huyghenian eyepiece	0	12	0
3261	88	25-mm. ×10 Huyghenian eyepiece	0	12	0
3262	88	17-mm. ×15 Huyghenian eyepiece	0	12	0
3266	88	45-mm. ×6 Compensating eyepiece	2	2	0
3267	88	30-mm. ×8 Compensating eyepiece	2	2	0
3268	88	22-mm. ×11 Compensating eyepiece	2	10	0
3269	88	15-mm. ×17 Compensating eyepiece	2	10	0
3270	88	10-mm. ×25 Compensating eyepiece	2	10	0
3275	68	Beck micrometer eyepiece	2	2	0
3263	73	Eyepiece with indicator	0	18	0
3264	73	Eyepiece with cross-wires	0	17	0
3273	73	Erecting eyepiece	1	10	0

LARGE SIZE EYEPIECES 1·41 INCH DIAMETER OF TUBE

3257	85	Eyeshade	0	2	0
3253	88	42-mm. ×6 Huyghenian eyepiece	2	5	0
3254	88	25-mm. ×10 Huyghenian eyepiece	2	5	0
3255	88	17-mm. ×15 Huyghenian eyepiece	2	5	0

APPARATUS FOR ILLUMINATING OBJECTS

3285	26	Small Abbe condenser, fitting with iris diaphragm on Microscopes No. 3210 and 3211	1	5	0
3285p	33	Set of patch-stops for above	0	7	6
3286	26	Large Abbe condenser in fitting with iris diaphragm and swing-out tray for colour screens with coloured and ground glass	2	10	0
3286p	33	Set of three patch-stops for above	0	7	6
3287	27	Beck dry achromatic condenser, 1 N.A., lenses only in mount, with standard object glass, screw thread	4	5	0
3288	27	Beck dry achromatic condenser, 1 N.A., complete in fitting with iris diaphragm and swing-out tray, grey and green glass	5	15	0
3288p	33	Set of three patch-stops for No. 3288 or 3290	0	7	6
3291	28	Beck dry and immersion achromatic and aplanatic condenser, 1·3 N.A., in mount, with iris diaphragm and tray for patch-stops and with ground and green glass double-wedge light moderator	9	15	0
3284	33	Traviss expanding iris patch-stop	0	12	6
3295	34	High-power dark-ground illuminator, optical portion only in mount, with standard object glass thread	2	0	0
3296	34	Illuminator as above in plain substage fitting	2	10	0

No.	Page		£	s.	d.
3297	34	Illuminator as above in centring substage fitting	3	5	0
3298	34	Stop to fit 1/12-in. oil-immersion object glass to reduce aperture for dark-ground illumination	0	2	6
3293	35	Beck patent focussing dark-ground immersion illuminator in plain substage fitting . .	5	7	6
3294	35	Ditto, in centring substage fitting . . .	6	2	6
3215	38	Bull's-eye condenser, 2¼-in. diameter, on heavy stand, with full adjustments . . .	2	10	0
3216	38	Bull's-eye condenser, 1½-in. diameter, on smaller stand with full adjustments . .	1	5	0
3360	40	Parabolic reflector	2	2	0
3361	40	Parabolic reflector with Sorby reflector . .	2	17	6
3362	40	Thin glass reflector	1	7	6
3363	41	Thin glass vertical illuminator . . .	1	7	6
3364	41	Prism illuminator.	1	17	6
3328	32	Double-wedge light moderator . . .	3	17	6
3366	43	Colour trough	2	10	0
3335	44	Paraffin lamp	2	15	0
3330	46	Beck electric lamp, complete with bull's-eye condenser, ground glass, signal-green glass, and metal filament 60 candle-power lamp .	8	10	0
3331	46	Beck electric lamp as No. 3330, but with 100 candle-power half-watt lamp . . .	9	0	0
3332	46	Beck electric lamp as No. 3330, but with "Pointolite" electric lamp, with resistance to work off direct current from 100 to 250 volts	14	15	0
3333	42	Set of 9 Wratten & Wainwright's colour screens, for use with above lamps, comprising: light blue, to give daylight colour, No. 78; dark blue, dominant wave-length, 5,000; blue-green, dom. wave-length, 4,700; light green, dom. wave-length, 5,500; green, dom. wave-length, 5,350; yellow, dom. wave-length, 6,000; orange, dom. wave-length, 6,300; red, dom. wave-length, 6,500; neutral tint, passing 1/10	3	12	6
—	42	Single filters, as above . . . each	0	6	6
—	—	Stand to hold two filters, as above . .	1	10	6
	—	Circular screens to fit substage rings can be supplied . . . . . each	0	5	6
3337	48	Incandescent gas lamp	2	5	0
	—	Extra mantles	0	1	0
3338	48	Incandescent spirit lamp	2	17	6
	—	Extra mantles . . . . . each	0	1	0
3336	45	Electric lamp on stand to take ordinary bulb .	1	10	0

APPARATUS FOR HOLDING SPECIMENS

3307	51	Sliding ledge	0	14	0
3305	99	Detachable mechanical stage, as illustrated on Microscope No. 3213 (page 99) . . .	6	0	0
3306	52	Concentric rotating mechanical stage, as illustrated	12	0	0
3400	52	Glass slips, 3 × 1, best quality, ground edges, approximate thickness 1 mm. per doz.	0	0	9
		per gross	0	8	6
3401	52	Ditto, second quality, ground edges per doz.	0	0	7
		per gross	0	6	6

No.	Page		£	s.	d
3405	55	Glass slips, 3 × 1, ground edges and excavated hollow . . . . . per doz.	0	1	6
3390	53	Cover glasses, No. 1, average thickness ·006, circular . . . . . per oz.	0	7	6
3391	53	Ditto, square . . . . . per oz.	0	6	0
3392	53	Cover glasses, No. 2, average thickness ·008, circular . . . . . per oz.	0	6	0
3393	53	Ditto, square	0	4	6
3394	53	Cover glasses, No. 3, average thickness ·01, circular	0	4	6
3395	53	Ditto, square	0	3	6
3388	53	Micrometer screw gauge for measuring thickness of cover glass slips, etc.	3	3	0
3406	54	Glass slips with ledge	0	0	6
3409	55	Cells, metal, circular . . . per 100	0	6	0
3410	55	Cells, glass. . . . . per doz.	0	5	0
3412	56	Troughs on 3 × 1 slips, small . . .	0	1	0
3413	56	Troughs on 3 × 1 slips, larger . . .	0	2	0
3414	56	Troughs on 3 × 1½ slips	0	2	6
3415	56	Tirough, 1½ × 1¼ × ¼ in.	0	4	6
3416	56	Beck's glass trough	0	9	0
3420	57	Live box	0	8	6
3321	57	Rousselet's live box	0	17	6
3421	57	Beck compressor	1	1	0
3422	57	Stage forceps	0	14	0
3425	58	Case of apparatus for holding objects, including 3 slips, 2 slips with hollow, slip with ledge, trough on 3 × 1 slip, Beck's glass trough, Beck's compressor, stage forceps, live box and thin glass	3	15	0
	—	Xylol . . . . . 2 oz.	0	1	6
	—	Benzol . . . . . 2 oz.	0	1	6
	—	Canada balsam, pure, in benzol or xylol 25 gr.	0	2	6
	—	Hollis glue . . . . . per bottle	0	1	0
3386	58	Turntable	1	1	0
3325a	59	Thoma-Hawksley Hæmacytometer, with two pipettes and covers in case. . . .	2	10	0
3325b	59	Ditto, but with Zappert, Türck, Füchs and Rosenthal, or Breuer ruling . . .	2	12	6
3325c	59	Ditto, Bürker model	3	10	0
3325s	61	Hæmacytometer chess-board pattern squared glass plate to drop into eyepiece, 25 squares of 1 mm., 9 squares of 2 mm., or squares over entire field either ¼ mm., ½ mm., 1 mm., or 2 mm. . . . . each	0	12	6
3222	61	Counting chamber for use with chess-board .	0	2	6
3223	59	Pipette for red corpuscles	0	7	6
3224	59	Pipette for white corpuscles	0	7	6
3274	63	Microspectroscope eyepiece	1	15	0
3384	62	Simple warm stage	0	7	6
—	64	S.I.R.A. wax, per stick 6 × ½ in. . . .	0	1	6
1290	64	Beck grinding and polishing machine for preparation of metallurgical specimens; standard machine without motor, with one polishing disc, cover, catcher, disc-lifter, 12 feet connecting wire plug adapter, and tin of grease	21	0	0
1292	64	Extra polishing discs	1	15	0
		Motors fitted at makers' current prices.			

No.	Page		£	s.	d.
3429	65	Pipettes	0	0	3
3430	65	Pipettes, glass, with teat . . . each	0	0	6

DISSECTING INSTRUMENTS

3431	—	Blow-pipes with stiletto	0	1	6
3432	—	Razor, hollow ground one side, flat the other	0	2	9
3433	—	Scalpels, with ebony handles, in three sizes of blade . . . . . each	0	2	9
3434	—	Needles in wooden handles with ferrule	0	0	6
3435	—	Needles in bayonet shape in wood handles	0	0	3
3436	—	Platinum needles in glass handles	0	2	0
3437	—	Scissors, curved	0	6	6
3438	—	Scissors, elbow	0	5	6
3439	—	Scissors, straight, 4-inch, with fine points	0	4	6
3446	—	Scissors, straight, 4½ inches	0	3	6
3441	—	Scissors, straight, 6 inches	0	5	6
3442	—	Seekers in ebony handles	0	0	9
3443	—	Chain hooks	0	3	0
3444	—	Forceps, without guide pin, 4½ inches	0	2	6
3445	—	Forceps, without guide pin, 6 inches	0	5	0
3446	—	Forceps, with guide pin, 2½ inches and 4 inches	0	5	9
3447	—	Forceps, Cornett's cover glass	0	2	6
3448	—	Section lifter, copper	0	0	6
3449	—	Section lifter and seeker combined, nickel plated	0	1	0
3450	—	Metallic hone, for sharpening razors, scalpels, etc.	0	2	6
3451	—	Case of dissecting instruments, consisting of three pairs of scissors, two scalpels, razor, two pairs of forceps, combined seeker and section lifter, blow-pipe, two needles, pipette with teat, magnifier, in walnut case	2	5	0

COLLECTING APPARATUS

3452	66	Tow-net for collecting marine specimens, 11 inches diameter, with fine muslin bag and bottle attached, with 24 yards stout cord on wood frame	0	15	0
3453	66	Ditto, made of bolting silk	1	12	6
3454	—	Dredge for bottom sea collecting, canvas and net bag, 10 inches	0	18	6
3455	—	Ditto, 14 inches	1	2	6
3456	—	Ditto, 16 inches	1	10	0
3457	—	Ditto, 18 inches	1	17	6
3458	—	Ditto, 24 inches	2	5	0
3459	66	Collecting stick with inner lengthening rod, total extension 5 feet 6 inches, polished cane with crook handle	0	13	6
3460	66	Net ring for attaching to above, 5 inches diameter, with bolting silk net and bottle	0	5	6
3461	66	Ditto, but with 6-inch diameter net	0	7	6
3462	66	Flanged tube for collecting nets	0	0	6
3463	—	Cutting hook for cutting weeds	0	3	6
3464	—	Collecting bottles, 6 inches × 1 inch per doz.	0	3	6
3465	—	4 inches × 1 inch per doz.	0	3	0

No.	Page		£	s.	d.
3466	—	Collecting bottles, 3 inches × 1 inch . per doz.	0	2	9
3467	—	3 inches × $\frac{3}{4}$ inch . . . per doz.	0	2	0
3468	—	2 inches × $\frac{5}{8}$ inch . . . per doz.	0	1	6
3469	—	$1\frac{3}{8}$ inch × $\frac{1}{2}$ inch . . . per doz.	0	1	0

SUNDRY APPARATUS

3279	67	Glass plate ruled in squares	0	10	6
3277	67	Stage micrometer with engraved scale, 1/10 and 1/100 of a millimetre	0	12	6
3278	67	Stage micrometer with engraved scale, 1/100 and 1/1000 of an inch	0	12	6
3276	68	Eyepiece micrometer, glass plate to fit into eyepiece	0	10	6
3480	67	Glass scale with 100 divisions etched on in millimetres for use in making drawings . .	0	10	6
3265	73	Cross-wire for eyepiece.	0	5	0
3275	68	Beck micrometer eyepiece	2	2	0
3368	69	Beck horizontal camera lucida . . .	1	17	6
3369	70	Beck vertical camera lucida. . . .	2	10	0
3370	71	Abbe camera lucida	4	5	0
3371	71	Simple type of Abbe camera lucida . .	3	3	0
3375	71	Drawing table	0	15	0
3358	—	Iris diaphragm to fit between object glass and nosepiece.	1	15	0
3345	72	Polariscope for use on microscope . . .	3	10	0
3342	74	Photomicrographic camera, vertical type, with one dark slide, $\frac{1}{4}$-plate size . . .	3	3	0
—	—	Extra double plate-holders	0	13	6
3340	75	Photomicrographic camera, horizontal type, $\frac{1}{4}$-plate size, with one dark slide . . .	8	15	0
—	—	Extra double plate-holders	0	13	6
3343	75	Focussing glass	0	15	0
3483	63	Hand centrifuge with two test-tubes in aluminium covers	3	3	0

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